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JOINT ACTIVE SHOOTER PROTECTION AND RESPONSE (JASPR) SCENARIO MODELING AND ANALYSIS IN SUPPORT OF FORCE PROTECTION

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THESIS

JOINT ACTIVE SHOOTER PROTECTION AND RESPONSE (JASPR) SCENARIO MODELING AND ANALYSIS IN SUPPORT OF FORCE PROTECTION

by

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June 2020

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13. ABSTRACT (maximum 200 words)

The Joint Active Shooter Protection and Response (JASPR) is a DoD-proposed active shooter defeat system, designed to detect an active shooting, alert first responders, reduce response time, activate automatic door locks preventing further targeting by the active shooter and, as a result, decrease the number of lives lost during the shooting. Active shooter defeat systems have been sparsely studied in the literature, and JASPR has not yet been widely demonstrated to be effective. This research uses an agent-based model to compare lives lost during an active shooting with and without a JASPR system present. This research models how many total deaths there are, on average, according to the active shooter's choice of entrance location into a simulated building, shooter probability of hit, shooter firing rate, whether the shooter suicides at a random interval after the first shot, response time of first responders, number of bystanders in the vicinity of an active shooting, and whether a JASPR system is present. Analysis of the model results indicate that JASPR presence, shooter's choice of entrance location into the building, and whether the shooter suicides were the most critical in determining how many total lives were lost across 45,000 model replications. The results of this research are intended to help decision makers prioritize where and how an active shooter defeat system such as JASPR might be best deployed.

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JOINT ACTIVE SHOOTER PROTECTION AND RESPONSE (JASPR) SCENARIO MODELING AND ANALYSIS IN SUPPORT OF FORCE PROTECTION

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ABSTRACT

The Joint Active Shooter Protection and Response (JASPR) is a DoD-proposed active shooter defeat system, designed to detect an active shooting, alert first responders, reduce response time, activate automatic door locks preventing further targeting by the active shooter and, as a result, decrease the number of lives lost during the shooting. Active shooter defeat systems have been sparsely studied in the literature, and JASPR has not yet been widely demonstrated to be effective. This research uses an agent-based model to compare lives lost during an active shooting with and without a JASPR system present. This research models how many total deaths there are, on average, according to the active shooter's choice of entrance location into a simulated building, shooter probability of hit, shooter firing rate, whether the shooter suicides at a random interval after the first shot, response time of first responders, number of bystanders in the vicinity of an active shooting, and whether a JASPR system is present. Analysis of the model results indicate that JASPR presence, shooter's choice of entrance location into the building, and whether the shooter suicides were the most critical in determining how many total lives were lost across 45,000 model replications. The results of this research are intended to help decision makers prioritize where and how an active shooter defeat system such as JASPR might be best deployed.

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LIST OF ACRONYMS AND ABBREVIATIONS

ABM	agent-based model
AS	active shooter
CCW	concealed-carry weapon
DoD	Department of Defense
DOE	design of experiments
DP	design point
IQR	interquartile range
JASPR	Joint Active Shooter Protection and Response
NPS	Naval Postgraduate School
SEED	Simulation Experiments & Efficient Designs

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EXECUTIVE SUMMARY

Active shootings in the United States have steadily increased since at least 2000, as has the number of casualties resulting from these events (Blair & Schweit, 2014). The DoD has also experienced its share of active shootings and casualties, most notably in connection with the Fort Hood shooting by Nidal Hassan in November 2009 that resulted in 45 casualties, the Navy Yard shooting in September 2013 that resulted in 20 casualties, and a second Fort Hood shooting by Ivan Lopez in April of 2014 that resulted in 15 casualties. A host of other active shootings over the years resulted in further casualties (Blair & Schweit, 2014). There is little evidence suggesting that the number of active shootings and their attendant casualties will cease.

This research looks at a DoD system titled "Joint Active Shooter Protection and Response (JASPR)." JASPR is designed to detect an active shooting with a gunshot detector; notify bystanders in the vicinity of the active shooting with local alert sirens, signs, and emergency alarms; alert local first responders to the active shooting; and then safeguard bystanders and impede the movement of the active shooter with active door locks once the shooting commences. Earlier research at the Naval Postgraduate School (NPS) called for such a system to reduce active shooting casualties by allowing bystanders to react faster and reduce the time required to summon first responders (Ergenbright & Hubbard, 2012). However, there is little-to-no published research on how effective such a system might actually be in practice. This research expands on unpublished work (McDonald, 2019) previously conducted at the NPS Simulation Experiments & Efficient Designs (SEED) Center for Data Farming, by estimating how effective JASPR is under a simulated agent-based model (ABM).

Agent-based models capture how multiple different simulated autonomous entities ("agents") in a virtual environment react over time to simulated events and other agents (Macal & North, 2010). The model in this study specifically captures agent behavior between an active shooter agent and bystander agents across a hypothetical location based on the second floor of the U.S. Military Academy Preparatory School at West Point, NY (see Figure 1). The active shooter enters the second floor at one of three locations, opening

fire at bystanders in either the dorm rooms, cafeteria, or classrooms section of the building, and continuing to fire while moving across the building according to a predefined set of waypoints. Bystanders in the building then flee to the nearest exits or attempt to hide or take cover in the rooms or classrooms to avoid the shooter.

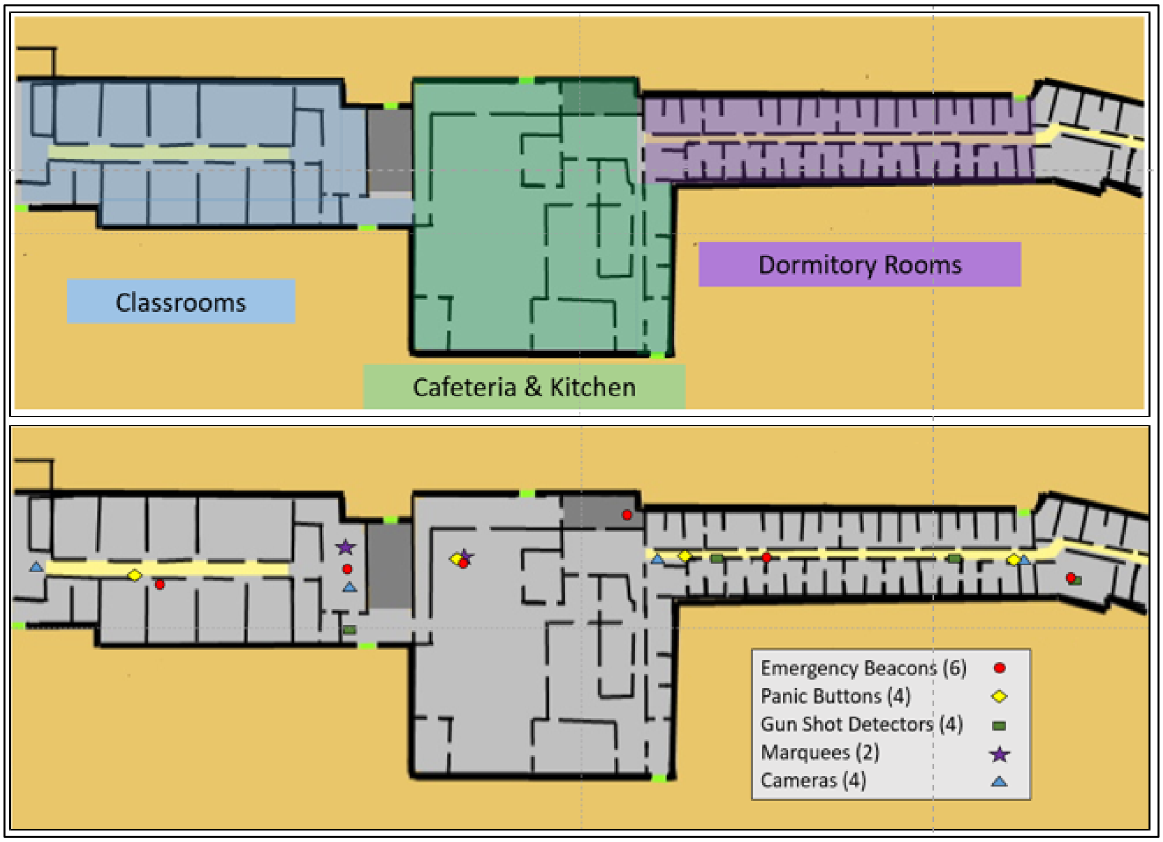

Diagram shows the different sections of building (top), and locations of JASPR components in building (bottom).

Figure 1. Second Floor of USMAPS Building at West Point, NY

The model simulates 45,000 active shooter incidents while systematically varying active shooter entrance, JASPR presence, active shooter decision to suicide, time until first responder response to the event, active shooter probability of hitting the intended target, active shooter rate of fire, and the number of bystanders at each of the building sections (classrooms, cafeteria, dorm rooms). All variables are examined systematically using an experimental design to reduce variable collinearity. The results of these active shooter incidents are collectively analyzed to determine how effective JASPR, along with each of the other variables, is at reducing Total Deaths.

Figure 2 shows a set of boxplots capturing Total Deaths at the end of each active shooter incident if a JASPR system is not present (left set of six boxplots), compared to bystander deaths if a JASPR system is present (right set of six boxplots). The boxplots are also color coded by shooter entrance location (green for cafeteria, blue for classroom, purple for dorm rooms), and are further separated by whether or not the active shooter suicided.

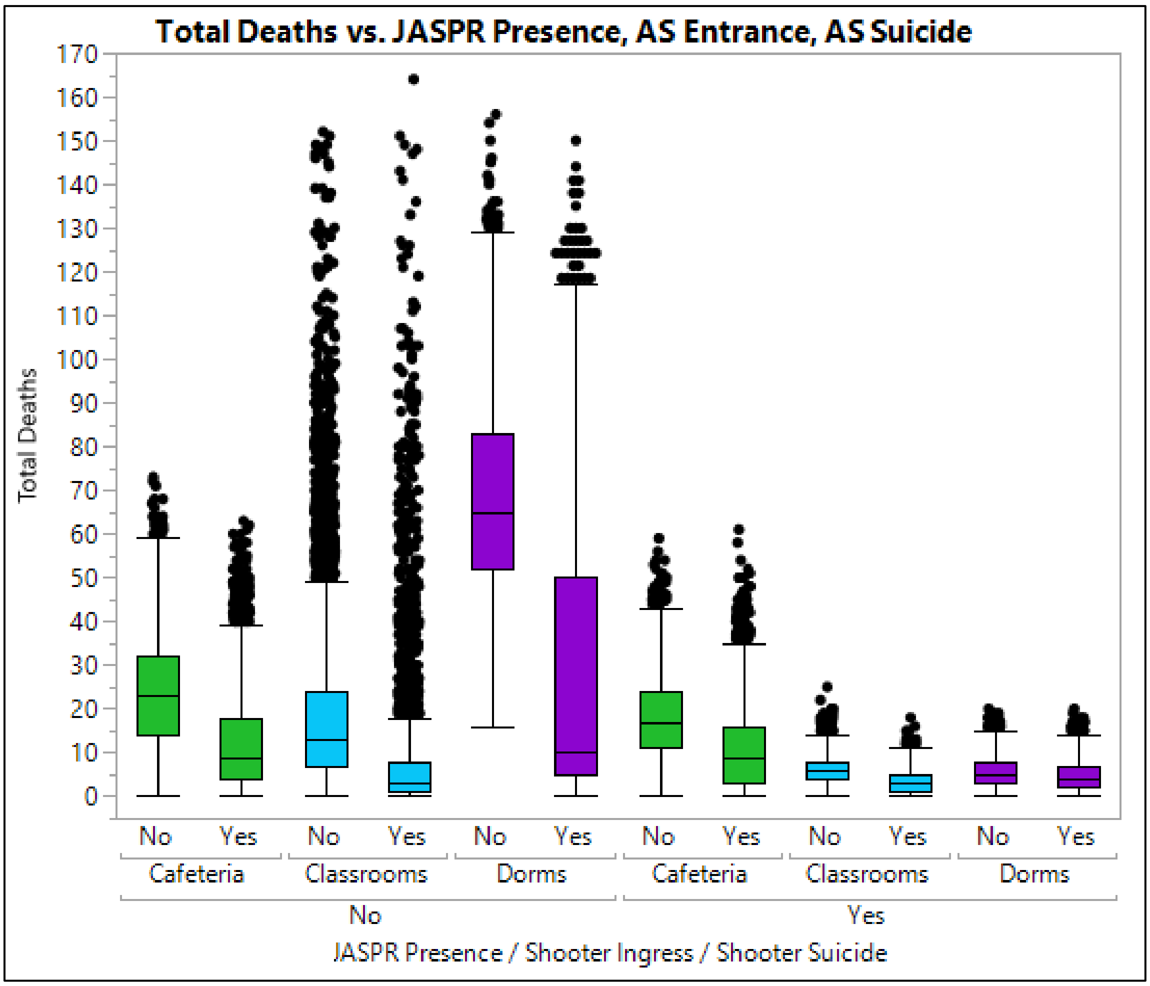

Figure 2. Total Deaths versus Three Categorical Variables

Figure 2 reveals several key insights regarding the JASPR system and its effectiveness at reducing Total Deaths, the effect of the active shooter's choice of entry location into the building, and the degree of effect the shooter's suicide has on Total Deaths. Key findings include the following:

- Total deaths are dramatically lower when the JASPR system is present, and other analyses of the model's results confirm this. Moreover, the model suggests that JASPR's presence is the single most critical factor for reducing Total Deaths. This effect is seen by comparing the left half of Figure 2 (Total Deaths without JASPR Presence) against the right half of Figure 2 (Total Deaths with JASPR Presence).
- The active shooter's choice of entry location matters significantly, as the contrasting results in Total Deaths indicates. JASPR is most effective at reducing Total Deaths when the active shooter begins firing at bystanders located inside their dorm rooms. The dorm rooms are isolated and present a small but relatively continuous set of targets for the active shooter to engage. Bystanders targeted by the active shooter in these scenarios are typically unable to alert first responders or the rest of the building before dying, which leads to a comparatively larger numbers of deaths. When JASPR is activated however, doors are locked and the active shooter's access to more targets is blocked.
- The difference JASPR makes in Total Deaths for the cafeteria scenario and classroom entrance scenario is smaller compared to the dorm room entrance scenario. In the cafeteria entrance scenario, many targets are presented to the shooter simultaneously. This set of targets has a collectively higher chance of avoiding the shooter, alerting the rest of the building, and summoning first responders more quickly.

- The classrooms entrance scenario shows a middle ground for Total Deaths between the cafeteria and classroom entrance scenario. The classroom section has larger rooms and a greater population density compared to the dorm rooms. Conversely, the classroom section has more rooms and is typically less densely populated than the cafeteria.

Although the results presented in this study are limited to the model they are based on, JASPR's potential in this study suggests more research into a set of active shooter defeat mechanisms is warranted. Ultimately, such research may reduce the scale of such horrific events—and, at least in some cases, prevent them.

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To my mother, father, sister, and nephews—Beatriz Lovejoy, James Lovejoy, Patricia Lovejoy, Aidan Calderon, and William Calderon— I love you.

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THESIS DISCLAIMER

The reader is cautioned that the computer programs presented in this research may not have been exercised for all cases of interest. While every effort has been made within the time available to ensure that the programs are free of computational and logical errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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I. INTRODUCTION

At approximately 4:15 pm on April second, 2014, Army Specialist Ivan A. Lopez shot his Smith & Wesson .45 pistol at 15 Soldiers across five separate locations, wounding 12 and killing three. Shortly after he opened fire, Lopez was narrowly prevented from entering a nearby conference room at his unit's headquarters office building and taking more lives when another Army Sergeant First Class physically barricaded the door (Tan, 2015). Lopez committed suicide after he was confronted by Military Police (MPs) at approximately 4:25 pm, just 10 minutes after he began shooting.

This was not the first instance of what people now term an "Active Shooting" at Fort Hood. On November 5, 2009, just a few years earlier, MAJ Nidal Hasan fired a pistol to kill 13 (plus an unborn child) and injure at least 30 other people at Fort Hood's Soldier Readiness Center (SRC) (McFadden, 2009). Civilian police shot MAJ Hasan multiple times as he pursued a wounded victim who had begun moving away from the SRC; we can only speculate whether MAJ Hasan would have continued his rampage.

Active shootings and their concomitant losses of life are certainly not unique to Soldiers on Fort Hood, TX, or to the U.S. military. In a formal study jointly sponsored by the FBI and Texas State University, more than 160 active shootings in the United States are noted between 2000 and 2013 (Blair & Schweit, 2014). The study included the Washington Navy Yard shooting on September 16, 2013, with 12 deaths and an additional seven injured; a U.S. Army recruiting center shooting on June 1, 2009, with one death and one injury; and a shooting at the Pentagon on March 4, 2010, with no deaths and two injuries. Further shootings in the report include such infamous names as the Columbine High School shooting (13 deaths, 21 wounded) on April 20, 1999; the Virginia Tech shooting (32 deaths, 17 wounded) on April 16, 2007; the Sandy Hook Elementary School shooting (28 deaths, two wounded) on December 14, 2012; the Aurora, CO, movie theater shooting (12 deaths, 70 wounded) on July 20, 2012; and, of course, multiple other active shootings over the years to the present. In response, a host of proposed solutions to active shootings over the decades have sought to blame or fix a range of issues in order to address the problem: the mental health of possible shooters, universal background checks for gun purchasers, increased security at possible events and locations, increasing or decreasing the availability of firearms to the general population, training and arming teachers to react to an event, active shooter reaction drills, electronic mass warning systems, and others. This research is intended to examine a more immediate solution to an active shooting.

A. RESEARCH PROBLEM

A comparatively small amount of research has been conducted over the years on more technologically sophisticated means to detect an active shooting in progress, alert first responders and bystanders, and ultimately reduce the number of casualties, or potential casualties, from an active shooting. Research by Ergenbright and Hubbard in 2012 spurred proposals to the Department of Defense (DoD) for a network of active shooter defeat mechanisms. Though Ergenbright and Hubbard originally titled such a system a “Victim Initiated Mitigation System,” the system fielded by the DoD is now termed the “Joint Active Shooter Protection and Response” (JASPR) system, or simply “JASPR” (Ergenbright & Hubbard, 2012). JASPR is designed to detect an active shooter, alert local first responders and bystanders in the vicinity to the presence of an active shooter, potentially isolate the shooter, and ultimately reduce the number of casualties during an active shooting. JASPR’s components, discussed with more detail in the next chapter, interact to reduce the threat posed by an active shooter.

JASPR’s success at reducing overall casualties may be more or less effective depending on a number of other factors. Factors that may affect JASPR’s success might include where the active shooter begins firing, how many people are in the vicinity of the active shooting, the duration of the active shooting, how rapidly the shooter fires, how accurate the shooter is, whether the shooter commits suicide, and a host of other possible factors. Just one early study into the effectiveness of JASPR has taken place (McDonald, 2019). McDonald’s study used Pythagoras, a government owned agent-based modeling (ABM) program, to simulate an active shooter event. The Literature Review of this thesis discusses McDonald’s previous research. However, further research is necessary to understand whether a JASPR presence at an active shooting, or some other factor or combination of factors, may contribute most to an overall reduction in active shooting casualties and reduce the potential loss of life in these scenarios.

B. RESEARCH QUESTION

How effective is JASPR at reducing the total number of deaths in an active shooting, given the many possible factors that might influence this? The analysis provided in this thesis may assist in quantifying JASPR's effectiveness under various conditions, illuminating where the greatest potential exists to reduce the duration of an active shooting, thus resulting in fewer lives lost and reduced costs to the DoD in terms of property damage and lost operational tempo.

C. THESIS STRUCTURE

The Background section provides an in-depth description of the JASPR system, including its proposed components, their purpose, and a small discussion of how JASPR was developed. Previous research conducted at the Naval Postgraduate School (NPS) Simulation Experiments & Efficient Designs (SEED) Center in Monterey, CA, is highlighted.

The Literature Review for this thesis focuses on the characteristics of an active shooting, including a review of what the "typical" active shooter in the United States looks like, frequent locations for active shootings, weapon types used in active shootings, the effectiveness of first responders to the shootings, and the frequencies and severity of active shootings. The insights summarized within this section are used to identify critical variables worth examining via a designed experiment. Additionally, other attempts to simulate active shootings using an ABM and their main conclusions are reviewed.

The Methodology chapter covers the model and design of the experiment. Context for the ABM is provided, and the independent variables, identified from the Literature Review chapter, as well as the conditional variables and main response, are discussed. An explanation of the design of experiments employed to obtain the data generated by the ABM and the main analytical techniques to evaluate the data is provided.

The Results and Analysis chapter describes the data that resulted from the designed experiment ABM and what the implications are for effective deployment of JASPR. The main response variable, Total Deaths, the effects of each of the independent variables on Total Deaths, and the analytical techniques indicated in the Methodology chapter are conducted on the data.

The Discussion chapter identifies the critical findings from the Results and Analysis chapter to answer the research question. Additional insights gained from the analysis are also described.

The Conclusion provides a synthesis of the main insights into how effective JASPR is at reducing the number of deaths from an active shooting under various circumstances, and suggests where and under what circumstances JASPR would likely be most effective.

II. BACKGROUND

A. PREVIOUS RESEARCH INTO JASPR

Mary McDonald of the NPS SEED Center conducted the initial, but unpublished, experimental research into JASPR in late 2019. Her efforts included the creation of an ABM (similar to the one used in this thesis) to simulate an active shooting at the USMAPS building at West Point, NY, to understand which of multiple JASPR components are the most effective in disrupting an active shooter's rampage.

McDonald's research examined five cases, known colloquially in the military as courses of action (COAs), for JASPR effectiveness at the dormitory section of the USMAPS building (2019). The characteristics of these five cases differ in the availability of "layers" of individual JASPR components. Case 1 uses no JASPR components. Case 2 uses alert beacons coupled with a text-to-speech (TTS) feature, LED marquees, emergency duress buttons, and gunshot detectors. Case 3 includes all of the JASPR components from Case 2, but adds networked cameras and incorporates access controls to the building's doors. Case 4 includes all of the JASPR components from Case 3, but adds a squad tracking system (these types of systems are often abbreviated as a "Blue Force Tracking" (BFT) system within the military) with chat features and floor plan for the first responders to the active shooting. Case 5 includes all of the Case 4 JASPR components, but is divided into two separate 'sub-cases;' the first sub-case (called "5a") eliminates the gun shot detectors from Case 4, and the second sub-case (called "5b") includes the gun shot detectors, but eliminates the emergency duress buttons from Case 4. These particular cases were requested by the JASPR office, for whom the study was conducted. Figure 1, taken from a briefing to the JASPR office, contains the mean values for the JASPR system's trigger time, first responder notification time, first responder response time, time the active shooter was killed, and the number of victims shot.

Case	System Triggered (min)	FirstResp Notify Time (min)	FirstResp Arrival Time (min)	Time Shooter Killed (min)	Victims Shot
COA 1 No JASPR	0	7.5	12.9	17.6	40.6
COA 2 Beacons/Marquis/ TTS/PanicButtons/GSD	1.8	1.8	7.1	13.6	28.9
COA 3 Add Cameras and Access Control	1.9	1.9	7.1	11.7	4.1
COA 4 Add BFT, chat, bldg floor plan	1.8	1.8	7.1	11.3	3.1
COA 5a WITH Panic Buttons, NO GSD	2.5	2.5	7.8	12.3	5.9
COA 5b WITH GSD, NO Panic Buttons	2.3	2.3	7.6	12.1	3.6

Figure 1. Mean Values by COA (for the Initial JASPR Research Results). Source: McDonald (2019).

McDonald's research not only suggests that JASPR might be effective at reducing the number of victims shot by an active shooter, but also suggests that different layers of JASPR components may be more, or less, effective at reducing the number of victims shot and reducing the response time to the scene of an active shooting. These results also suggested that the initial "base" layer of beacons, visual displays, gunshot detectors, and panic buttons (COA 2) provided the largest reduction in first responders notification time, though the additional layer containing cameras and access control via automatic door locks (COA 3) provided the greatest reduction in victims shot.

This thesis expands on this earlier research. While the same base ABM is used, additional variables are explored, including additional entrance options (class-room and cafeteria entrance) for the active shooter, the possibility of the active shooter committing suicide, a "cognitive delay" (explained more fully in the Literature Review) for bystanders, and variations on the location and total number of bystanders within the model. Finally, for the simulation runs conducted, the JASPR system presence is treated as a binary option (all or nothing), and not treated as layers of components as is the case in previous research.

B. JASPR COMPONENTS

JASPR in its proposed form relies on several components: alert beacons with text-to-speech capability, emergency duress buttons, LED marquees, warning lights in a variety of configurations, gunshot detectors, a first responder squad tracking system, and automatic door locks. Ideally, JASPR is the integrated functioning of each of these components, where the total system allows potential victims in the vicinity of a developing active shooting to signal the event and/or locates an active shooting by the sound of gunshots, alerts nearby bystanders of an in-progress active shooting with spoken warnings and visual cues, alerts first responders of the same shooting, automatically locks doors to prevent active shooter entrance, and allows first responders to closely coordinate their tactical approach as they move to respond to the shooting (or shooter). Examples of several proposed components for JASPR are provided by Alertus Technologies, Louroe Electronics, and TRX Systems, commercial security vendors that sell security technology. These vendors are listed here because the JASPR system proponent relied directly on these vendors to produce their version of a JASPR system. Pictures of the relevant sub-systems and components are provided with a short description of each technology. However, in the work the emphasis is on the capability that the technology provides, not the vendor selling the technology.

1. Alert Beacons

Alert beacons are described as "wall-mounted integrated audible visual notification appliance [s] with ultimate reliability" (Alertus Technologies, n.d.). The alert beacons are designed to flash or strobe when triggered, as well as to display messages sent to them. In an active shooting, the alert beacons will notify personnel and bystanders in the vicinity that (1) an emergency is taking place, (2) it is an active shooting, and (3) further details of the shooting and potential instructions will be given as available. An example alert beacon is shown in Figure 2.

Additionally, a text-to-speech option allows nearby personnel to hear a message corresponding to the written message displayed on the beacon's face. The additional spoken messages may reduce bystander cognitive delay and potentially improve reaction times.

Figure 2. Alert Beacon Example. Source: Alertus Technologies (n.d.).

2. Emergency Duress Buttons

Emergency duress buttons, also known as “Panic Buttons,” in JASPR are described as an “[i]mmediate, easy, single-point activation for emergency notification” (Alertus Technologies, n.d.). These buttons allow bystanders to respond immediately to an active shooting if an emergency duress button is nearby and the bystanders are physically capable of reaching the button. An example emergency duress button is shown in Figure 3.

Figure 3. Emergency Duress Button Example.
Source: Alertus Technologies (n.d.).

3. LED Marquees

The LED marquees are proposed as a method to “cost-effectively reach large indoor or outdoor public areas with emergency notifications” (Alertus Technologies, n.d.). The main function of the LED marquee is to provide written notification in the same way that an alert beacon would, but to provide the message in larger font in much larger spaces (e.g., lobbies, large seating areas). Presumably, the marquee’s visual reach in larger spaces would assist in crowd notification, encouraging bystanders to evacuate the building and avoid becoming victims when an active shooter is in the building. An example LED marquee is shown in Figure 4.

Figure 4. LED Marquee Example. Source: Alertus Technologies (n.d.).

4. Standalone Light and Sound Signals

Wall-mounted light and sound signals are another proposed technology within the JASPR system. Light signals provide a visual system to warn or caution local bystanders that an emergency is in progress. One problem cited by Stewart (2017) is the delay before bystanders realize an active shooting is occurring in their vicinity. A standalone light system flashing warning lights or emergency system sounds to a crowd may allow bystanders to react more quickly at a safer distance than the alert beacons or LED marquees, particularly for those in rooms out of sight range, but not necessarily outside of audible warning range. An example wall-mounted light and horn is shown in Figure 5.

Figure 5. Wall-Mounted Light and Horn Example.
Source: Alertus Technologies (n.d.).

5. Gunshot Detection System

Gunshot detectors use an embedded microphone to listen for gunshot sounds and alert first responders. One commercial vendor, Louroe Electronics, describes their system as recognizing "firearm discharge in various firearms in different settings. Within seconds of a gunshot, the software accurately classifies and triggers an immediate notification through VMS [video management systems]" (Louroe Electronics, n.d.). Security staff can then verify and reduce the reaction time of security personnel. The same vendor suggests the system has a detection range of 245 feet in a quiet environment, 100 feet in a normal environment, and 75 feet in a noisy environment, and it can be configured for "omni-directional, bidirectional, or directional" (Louroe Electronics, n.d.) sound. An example gunshot detector is shown in Figure 6.

Figure 6. Gunshot Detector Example. Source: Louroe Electronics (n.d.).

6. Squad Tracking System

A squad tracking system ideally links first response teams and enables them to coordinate an improved tactical approach in real-time to a building or site after an active shooting commences. Squad tracking technology should allow a team to enter a building at the appropriate location(s), block egresses for an identified active shooter, and allow first responders to notify each other when an active shooter has been apprehended or killed. At least one proposed vendor, TRX Systems, sells a system that allows continued operation of the system in Global Positioning Systems (GPS) denial situations, such as buildings with dense brick, concrete, or steel walls. An example squad tracking system is shown in Figure 7.

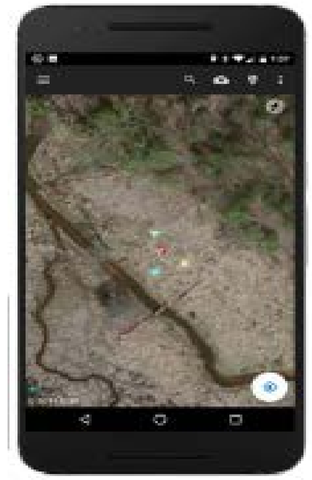

Figure 7. Squad Tracking System Example. Source: TRX Systems (n.d.).

7. Automatic Door Locking System

Automatic door locks integrated into JASPR will electronically lock on notification of an active shooting. The door locks will either prevent an active shooter from entering into a room or might require them to spend extra time destroying or disabling the lock, allowing bystanders additional time to escape and first responders to arrive. Automatic door locks, as they are currently proposed in JASPR, will also allow door egress; the automatic door locks, if they function as intended, will assist personnel fleeing or hiding from a shooter, but would retard shooter progress through a structure.

Automatic door locks are a possible ethical problem. Engaging door locks while bystanders are locked inside a room in close proximity to the active shooter would likely increase their probability of being victimized. Modeling this particular system may indeed show a reduction in overall lives lost during an active shooting, but at the cost of several bystander lives at the start of the shooting.

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III. LITERATURE REVIEW

This literature review is focused on describing and evaluating (1) the typical characteristics of an active shooting, (2) agent-based models of active shootings, and (3) previous recommendations made to thwart active shootings.

A. TYPICAL CHARACTERISTICS OF AN ACTIVE SHOOTING

One of the more in-depth and authoritative sources for defining a typical active shooting comes from the FBI and Texas State University's study where they reviewed 160 active shootings occurring between 2000 and 2013 (Blair & Schweit, 2014). Blair and Schweit adopt the FBI's definition of an active shooter as "an individual actively engaged in killing or attempting to kill people in a populated area" (FBI, n.d.a.), and further state that "implicit in this definition is that the subject's criminal actions involve the use of firearms" (Blair & Schweit, 2014). Part of this study is dedicated toward documenting the increasing trend in active shootings, where Blair and Schweit illustrated a clear increase in the number of active shootings over these years. It is worth noting the comparative increase in the number of bystanders killed over the same time period as well. The study observed "an average of 6.4 incidents occurred annually" (p. 8), but that "In the last seven years of the study, that average increased to 16.4 incidents annually" (p. 8). The FBI hosts updates to the 2013 report annually to show the most recent statistics on active shootings. Figure 8 shows the most recent update of their infographic indicating the number of shootings and total casualties over the years (Blair & Schweit, 2014). Visual inspection of Figure 8 suggests the increasing overall trend in frequency of active shootings and number of associated casualties.

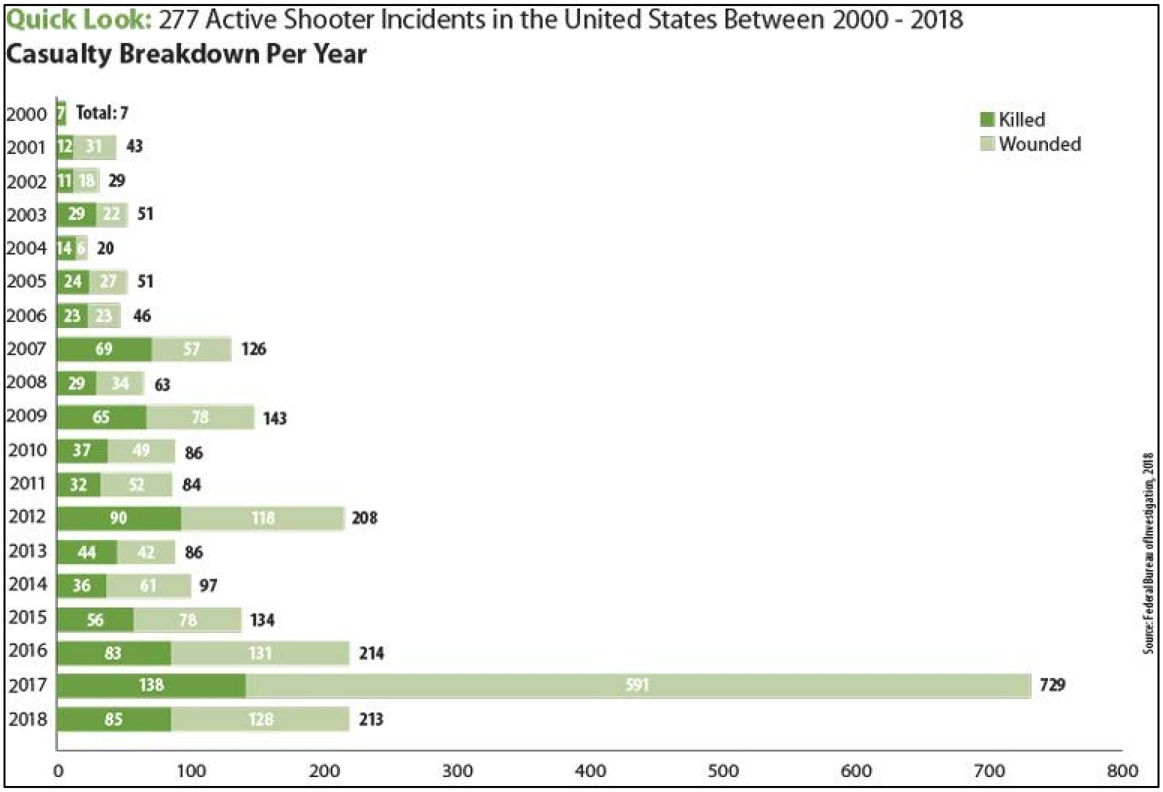


Figure 8. An Increasing Trend in Active Shooter Incidents and Casualties in the United States between 2000–2018. Source: FBI (n.d.b.).

In the study, several characteristics of active shootings are noted, including an increasing trend in shootings, typical shooting duration, number of shooters, and shooting locations (Blair & Schweit, 2014).

1. Active Shooting Duration

On review of a subset of cases where the duration of shootings was available, the 2014 Blair and Schweit study observed that most shootings are finished within several minutes: "In 63 incidents where the duration of the incident could be ascertained, 44 (69.8%) of 63 incidents ended in 5 minutes or less, with 23 ending in 2 minutes or less" (p. 8). Moreover, they noted that the majority of incidents "ended on the shooter's initiative before the police arrived—sometimes when the shooter committed suicide or stopped shooting, and other times when the shooter fled the scene" (p. 11).

2. Number and Gender of Active Shooters

The Blair and Schweit study observed that in just two of the 160 cases reviewed there are two shooters (2014). The remaining 158 cases are restricted to a single shooter. Additionally, of the total number of shooters, just six are female.

3. Active Shooting Locations

A plurality of the 160 active shootings identified by Blair and Schweit occurred at commercial locations (73), followed by educational institutions (39), and government (including military) properties (16) (2014). Blair and Schweit show that the remaining active shootings occurred in open spaces (15), residences (7), houses of worship (6), and healthcare facilities (4). Of the 16 government shootings cited, five of these occurred on military property. Figure 9 displays a pie chart indicating these active shooting locations by percentage.

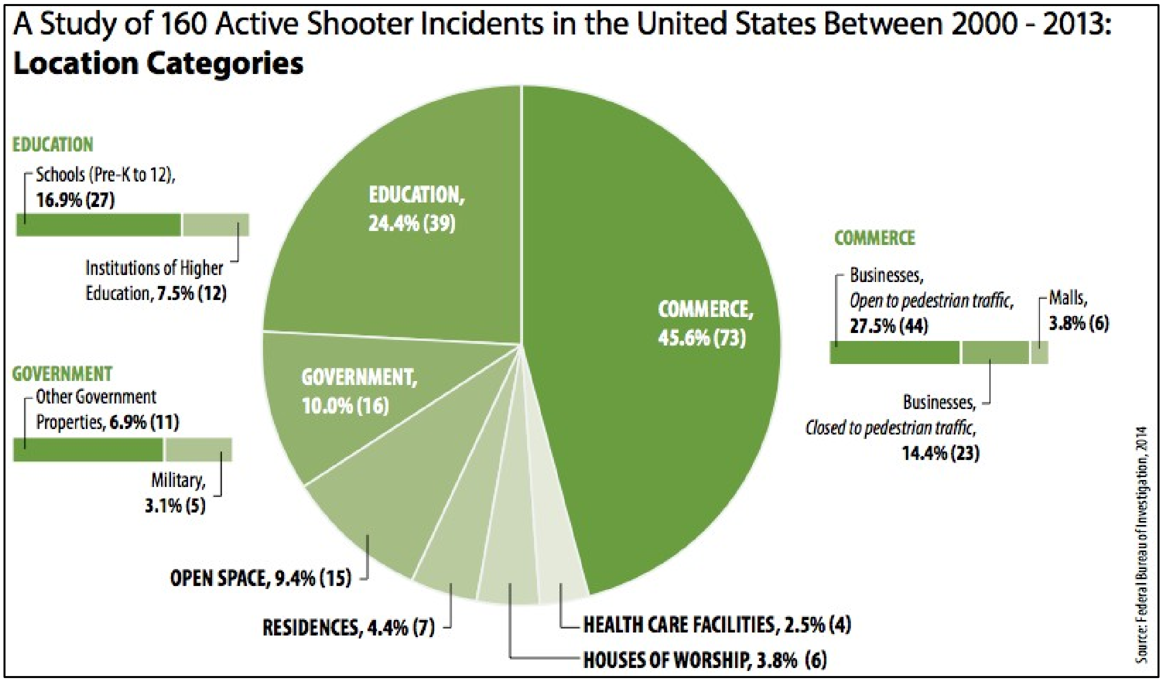


Figure 9. A Study of 160 Active Shooter Incidents in the United States between 2000–2013: Location Categories.
Source: Blair and Schweit (2014).

4. Active Shooter Probability of Kill

Of the 160 active shootings between 2000 and 2013, Blair and Schweit show that there are 1,043 casualties (not including the active shooter) (2014). Of these casualties, 486 are fatalities, while the remaining 557 are wounded. This suggests a probability of 0.47 kills per bystander hit, or p(Kill|Hit) = 0.47.

5. Typical Firearms Used

A majority of active shooters used nothing more powerful than a pistol, a minority used a rifle, and a smaller minority used a shotgun, per Blair et al. (2014). Blair et al. provide a convenient infographic, shown in Figure 10, to indicate the most powerful weapon used in 104 different active shootings.

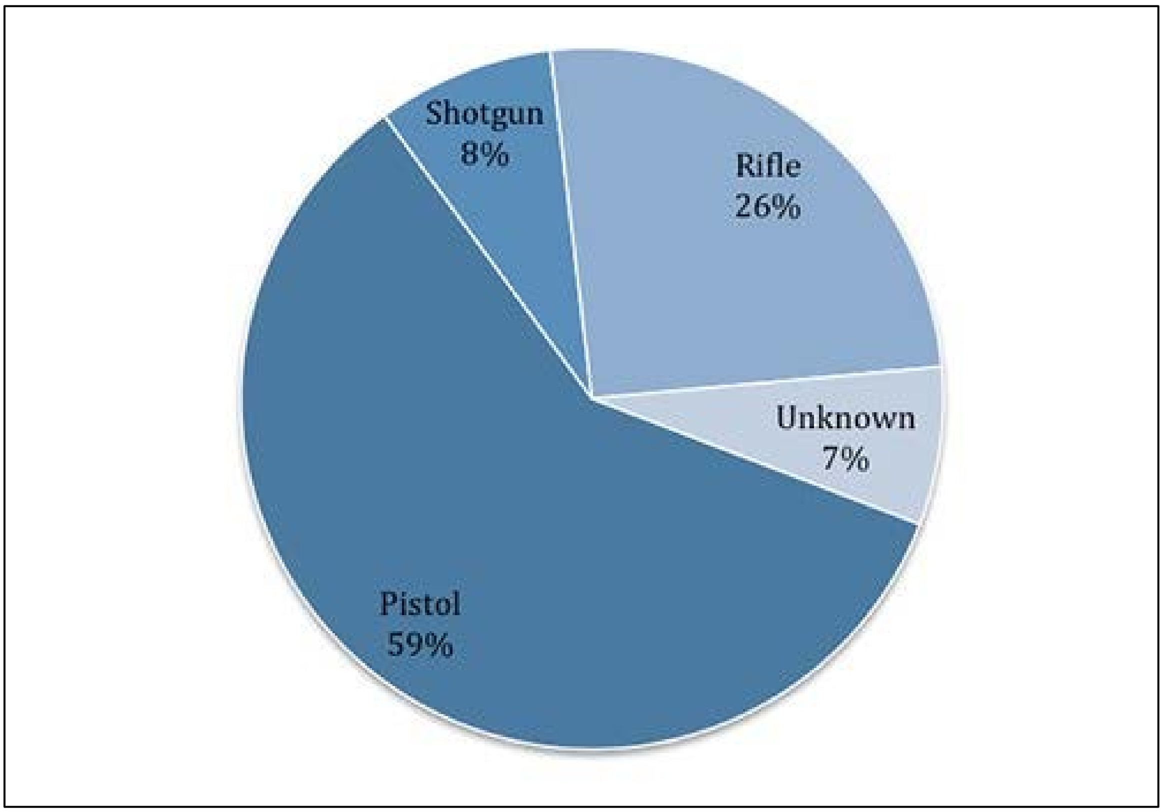


Figure 10. Most Powerful Weapon Used. Source: Blair et al. (2014).

6. Resolution

Blair et al. (2014) indicated that, in 51 active shootings out of 104 studied, the event concluded before the police arrived, with the attacker stopping by suicide or leaving of his own accord 34 times out of 51 and the remaining 17 times the shooter is stopped by the bystanders either shooting or subduing him. After police arrivals, the shooter is stopped by a police shooting or subduing him in 32 times of 53, and conversely, the shooter suicides or surrenders in the remaining 21 times without direct police action. Figure 11 summarizes how active shootings in Blair et al.'s study are resolved with a flowchart of outcomes.

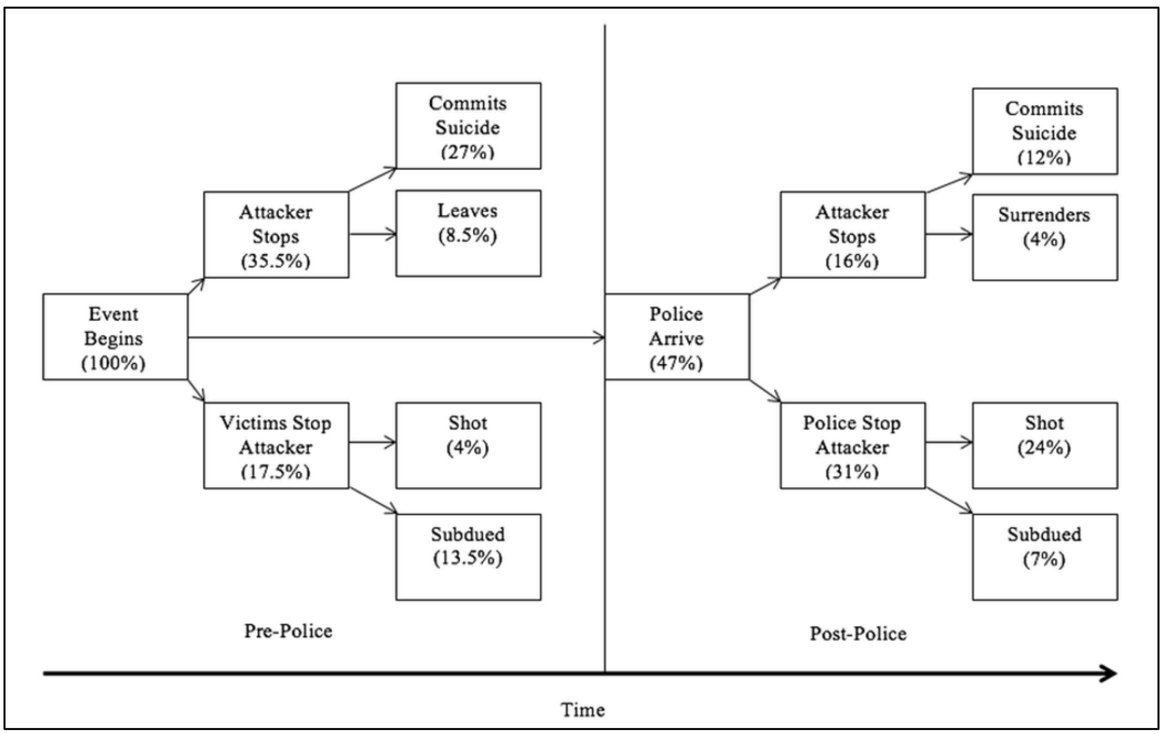


Figure 11. Active Shooter Event Resolution. Source: Blair et al. (2014).

In a significant number of events depicted by this flowchart, the active shooter suicides (44/104), and the majority of the suicides (29/44) occur before police arrival.

B. AGENT-BASED MODELS OF ACTIVE SHOOTINGS

Anklam et al. (2015) modeled a scenario showing civilian casualties over time after an active shooter enters a hypothetical school building, randomly selects either one of three classrooms, an office, or the school cafeteria, "shoots victims in 20-second intervals for two to five minutes before leaving and choosing another destination" (p. 10). The active shooter then moves to the next randomly selected location within the school until stopped. Anklam et al. varied whether 0%, 5%, or 10% of teachers or school staff carried a concealed-carry weapon (CCW), in this case a firearm, in order to rapidly respond to an active shooter incident, and whether the school retained an armed first responder on site to handle an active shooter incident. The authors show a decrease in casualties when either an armed first responder is on scene and able to confront the active shooter or a member of the school staff is able to confront the active shooter with their CCW. Figure 12 is a consolidated set of results, showing the higher number of casualties attributed to the lack of on scene bystanders with access to CCWs.

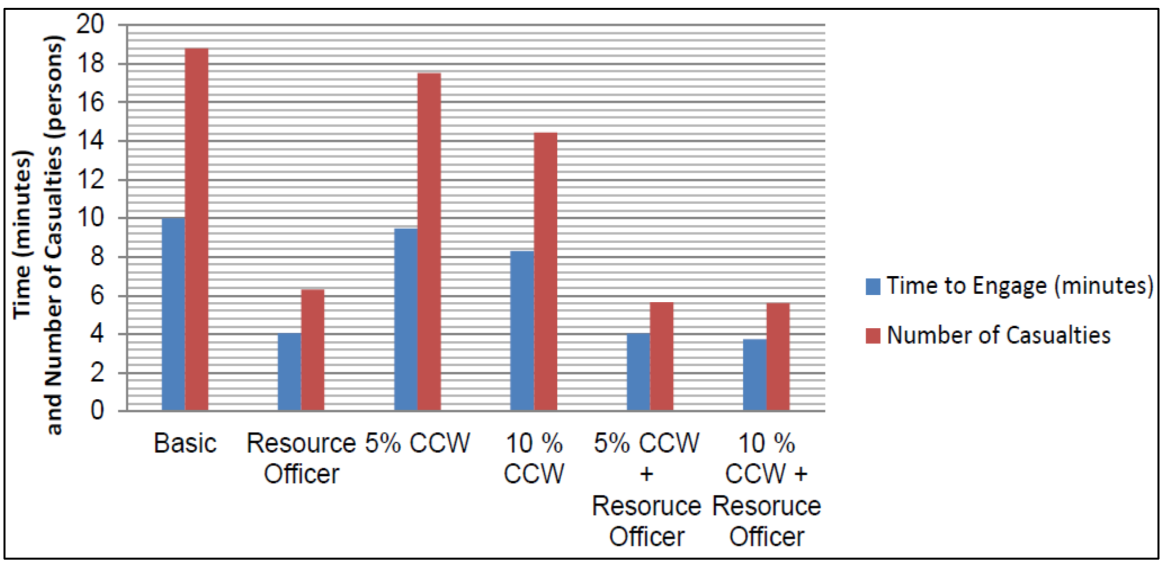


Figure 12. Consolidated Results on Casualties. Source: Anklam et al. (2015).

Hayes and Hayes (2014) created an ABM to understand how a proposed 2013 bill from the U.S. Senate might mitigate the number of civilians killed or wounded. Using a few rules for the active shooter, civilian, and security guard agents, they modeled casualty rates from both an indoor and an outdoor active shooting based on a set of parameters for (1) running speed, (2) number of bullets fired per second, (3) aiming deviation (for both gunman and security guards), (4) magazine capacity for the shooters, (5) gun range, and (6) "escape distance" (para. 3.7). Perhaps just as critically, Hayes and Hayes made a serious attempt to validate their model by successfully comparing their results against the data obtained from the Aurora, CO mass shooting by James Holmes (para. 3.17). Their model produced results indicating a linear, or nearly linear relationship between casualties and rate of fire, reproduced in Figure 13, though one of their most insightful discoveries may have been that the presence of one or more first responders (security guards) seems to dramatically reduce the number of people shot.

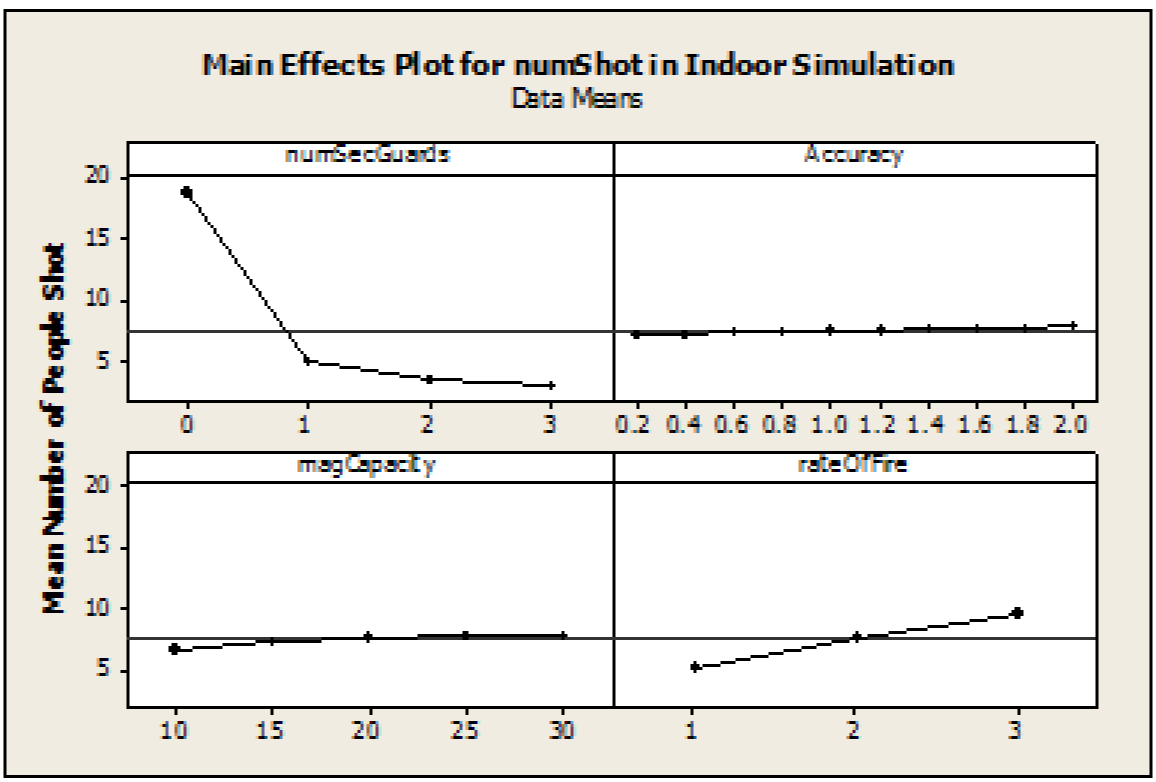
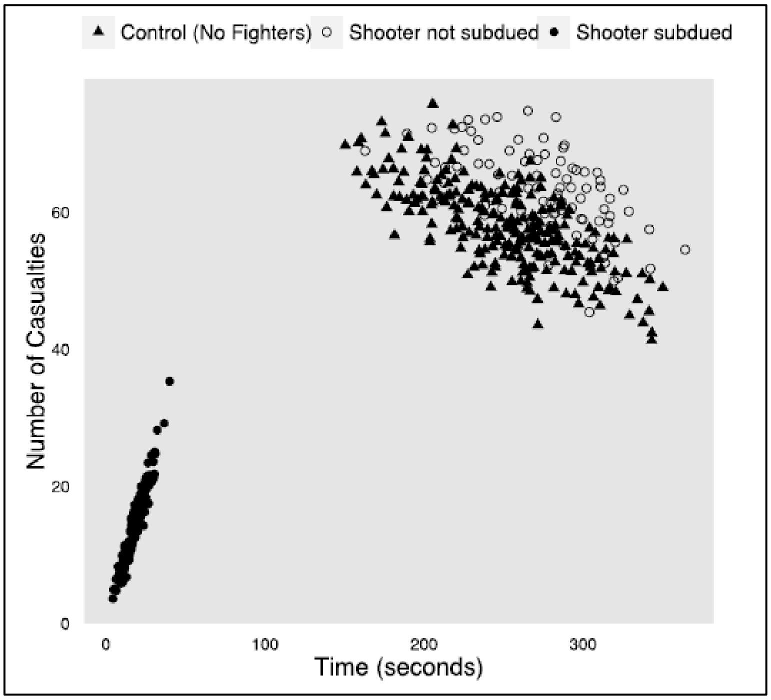


Figure 13. Main Effects Plot for Indoor Scenario. Source: Hayes and Hayes (2014).

Briggs and Kennedy (2016) modeled an active shooting scenario to address the effectiveness of bystanders choosing to fight against an active shooter. One of their most significant observations was to suggest that actively opposing a shooter (a "fight" response) tends to delay the shooter, and although it typically caused the fighters to become victims, even a small unarmed but coordinated group can dramatically reduce casualty rates in such events. They also note that their results support the conclusions drawn by Hayes and Hayes, stating "[t]he number of casualties sustained in each incident is directly related to time since the shooter has a sustained rate of fire of one round per second" (p. 3526), implying a relationship between casualties and the active shooting duration. Their results, graphically displayed in Figure 14, also strongly hint at a rapid increase in the number of casualties at the beginning of a mass shooting, followed by a peak and then a leveling-off of casualties, regardless of whether the shooter was subdued or not (though the subdued shooters failed to produce as many casualties).



Plot displays a random sample of 500 of 2000 models runs for ease of visibility.

Figure 14. Casualties by Simulation End Time in Control and Experimental Conditions. Source: Briggs and Kennedy (2016).

Stewart (2017) provides another agent-based model that evaluated civilian casualties by: “law enforcement response times,” “civilian response strategy [run, hide, or a combination of run and hide],” and the “cognitive delay” (time until event recognition) for the civilians involved in the incident. Stewart observed that quicker response times by law enforcement, a mix of running and hiding by civilians rather than adherence to one strategy, and reduced cognitive delays by civilians all tended to decrease casualty rates. Stewart concluded that mandatory active shooter training is most effective in reducing civilian casualties, followed by security guard intervention.

Finally, Lee et al. (2018) created an agent-based model to observe both civilian and first responder casualties in a scenario intended to reflect a large outdoor public event with up to 500 civilians in a 500-foot by 300-foot area, a physically isolated active shooter, and a police presence nearby, loosely reflecting the 2017 Las Vegas-style active shooting. They carried out their study, altering the four independent variables one-at-a-time: evacuation delay times (0–120 seconds), which loosely reflect a cognitive delay by the bystanders in their scenario, police response times (0–30 seconds), active shooter firing rates (1–60 seconds), and first responder firing rates (1–60 seconds). Lee et al. demonstrated a clear increase in civilian casualties with an increase in the active shooter’s firing rate, evacuation delay, and first responder delay. They also observed a decrease in civilian casualties with an increase in first responder firing rate. While they do not explicitly state this, their results suggest that most civilian casualties occur as a result of the active shooter firing rate, but the fewest casualties as a result of the cognitive delay. Figure 15 shows Lee et al.’s casualty rates against the length of evacuation delay.

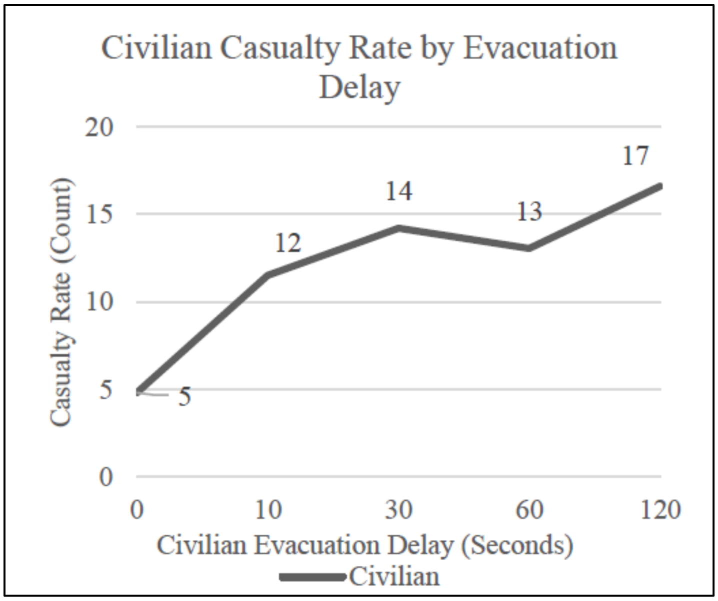


Figure 15. Casualties by Delay During an Active Shooting. Source: Lee et al. (2018).

C. RECOMMENDATIONS TO IMPROVE ACTIVE SHOOTING RESPONSES

Ergenbright and Hubbard (2012) examined 14 case studies of active shootings in the United States, one active shooting in Norway (Utoya Island), and the Oslo bombing. They note that the average active shooter event lasts roughly 12.5 minutes, while the average law enforcement response time to these incidents is 18 minutes. They also studied the corresponding active shooter's rates of kill in each case study and proposed three hypotheses after examining these case studies: (1) that the "Prevention/preemption of the active shooter alone is insufficient to reduce the rate of kill," (2) that "Law enforcement interdiction of the active shooter is insufficient to reduce the RK [rate of kill]," and, based on their first two hypotheses, that (3) "[a] victim initiated mitigation system will sufficiently synchronize immediate control measures with a prescribed set of automated and standardized responses in order to reduce the RK" (Ergenbright & Hubbard, 2012, pp. vii). They define a victim-initiated mitigation (VIM) as "A mechanism by which a victim or potential victim can initiate a combination of immediate mechanical lockdown responses accompanied with a standardized emergency response resulting in the containment and control of Target Areas and Threat Zones, as well as activation of a standardized Emergency Action Plan,” (p. xxi) and argue that such a system is “the only effective means of reducing the effects of an Active Shooter” (p. 2).

Whitney (2017) advocated for providing law enforcement and/or military tactics that “provide basic guidance in mindset, movement, and self-protection strategies that have the potential of improving the likelihood of survival of students, faculty, and staff alike” (p. vii). Although teaching military or law enforcement tactics to civilians may raise a substantial number of questions and issues, this line of thought complements the approach Briggs and Kennedy (2016) argue for, and this claim is supported in part by Stewart (2017).

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IV. METHODOLOGY

This chapter describes key operational details for the model, including its physical/ geographical location at the U.S. Military Academy Preparatory School (USMAPS) at West Point, NY, the location of each JASPR component employed in the model, the active shooter's probability of killing a bystander given a hit, agent movement rates, the active shooter's ammunition load, and the active shooter's firing range. This chapter also defines the independent and conditional variables used, the design of the experiment, and the software used for analysis.

A. MODEL PARAMETERS AND ASSUMPTIONS

1. Model Layout

The second floor of the USMAPS building at West Point, NY, provided the physical basis for the scenario in the ABM. The building provides multiple entrances and exits, two sets of stairwells, corridors, and differing room layouts, including dorm rooms, a cafeteria with kitchen, and several classrooms. Figure 16 illustrates the base map for the second floor of the USMAPS building and the different sections of the building, with the classrooms, cafeteria and kitchens, and dormitory rooms highlighted in blue, green, and purple, respectively. This color code is maintained throughout many of the graphics in the remainder of this thesis for easy comparison. Exits and entrances on the second floor are indicated in neon green.

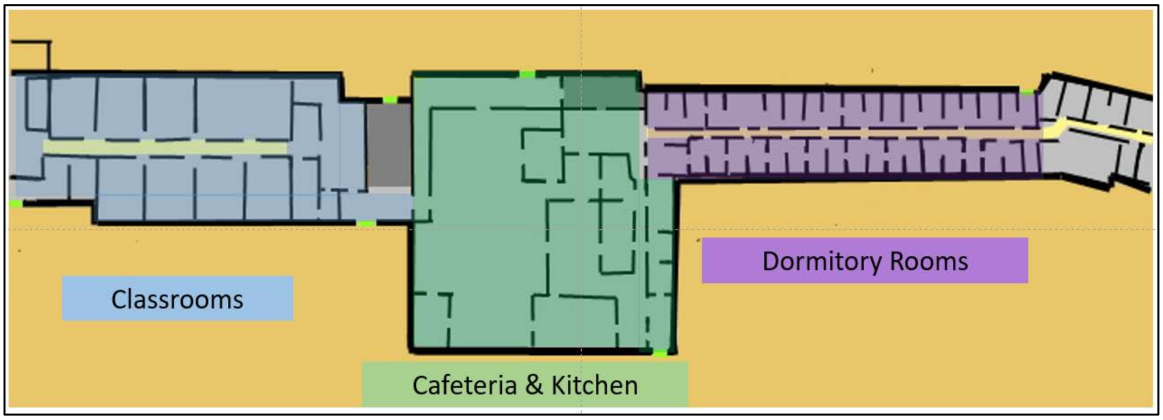

Figure 16. USMAPS Second Floor—Main Sections

2. Active Shooter Entrance Locations and Routes of Travel

Three entrance locations for the active shooter, roughly corresponding with the classrooms, cafeteria and kitchen, and dormitory sections of the building, are designated within the second floor of the USMAPS building. One entrance for the active shooter would likely not provide as diverse a set of outcomes for the experiment, and three separate and diverse entrance locations are thought to be sufficient to test the effect of an active shooter in each of the different locations of the building. More than three entrance locations would likely not provide much additional insight for this scenario. The active shooter moves along a path through the building, determined by a set of pre-determined waypoints, with some randomness and some propensity to veer off the path to shoot at and move towards individual bystanders.

a. Classroom Entrance

In the classrooms entrance scenario, the active shooter proceeds roughly west to east, checking for potential targets in the multiple classrooms located along the west wing. After exiting the classrooms section of the building, the active shooter enters the cafeteria section of the building and finally proceeds through part of the kitchen area and then stops at the cafeteria entrance. Figure 17 corresponds roughly with the active shooter's west wing/classrooms entrance and route of travel.

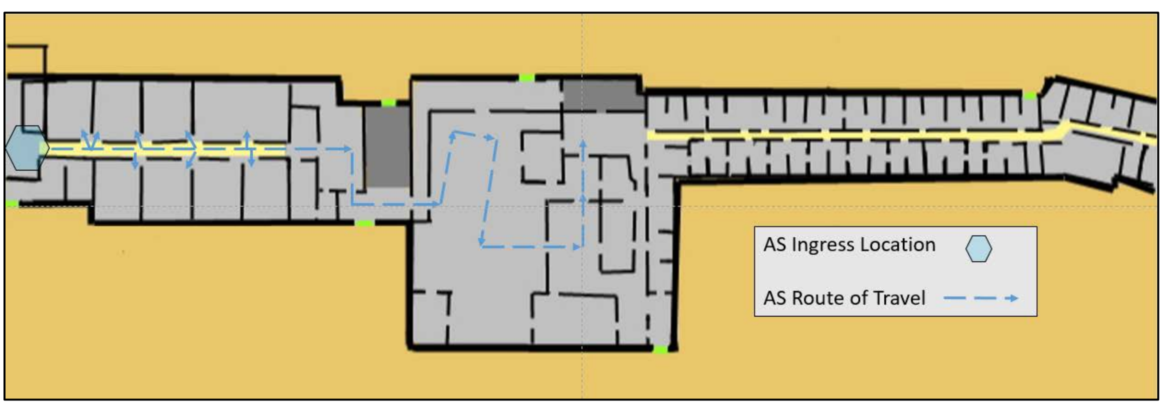

Figure 17. Active Shooter Entrance and Route of Travel for Classrooms

b. *Cafeteria Entrance*

In the cafeteria active shooter entrance scenario, the active shooter proceeds directly into the cafeteria, shooting as he moves roughly south, checks a back room within the kitchen, then proceeds west toward the classroom section of the building. This scenario is intended to show a "worst case" in which the active shooter opens fire into a crowded location. Figure 18 corresponds roughly with the active shooter's designated cafeteria entrance and route of travel.

Figure 18. Active Shooter Entrance and Route of Travel for Cafeteria

c. *Dorm Room Entrance*

In the dorm rooms entrance scenario, the active shooter enters the building at the east end of the dorm rooms section, then proceeds west along a narrow corridor, attempting to locate bystanders in each of the dormitory rooms. On exiting the dorm rooms section, the active shooter enters the kitchen, moves out to the cafeteria, exits the cafeteria, then enters the west wing with classrooms, and proceeds toward the western exit. Figure 19 graphically shows the active shooter's dormitory rooms entrance and route of travel through the building.

Figure 19. Active Shooter Entrance and Route of Travel for Dorm Rooms

3. JASPR Component Locations

The JASPR proponent determined suitable locations to place JASPR components, which included: beacons, cameras, gunshot detectors, marquees, and panic buttons. These locations are displayed with a symbol in legend Figure 20.

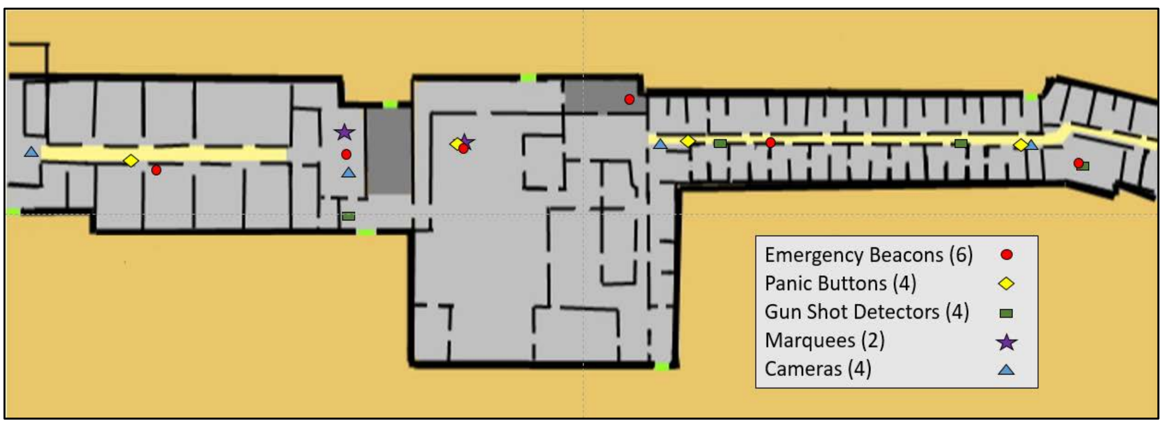

Figure 20. USMAPS Second Floor—JASPR Component Locations

4. Simulation Duration and Time Step

Each model run reflects a 30-minute time frame. This time frame is large enough to accommodate the 15-minute maximum for recorded First Responder Response Times to active shootings cited by Blair et al. (2014) and Blair and Schweit (2014).

Model time steps occurred every other second. That is, the modeling software used for this study provided updates to agents and events every two seconds.

5. Active Shooter Assumptions

a. Active Shooter Probability of Kill

The model uses a p(kill|hit) = 0.47, given the research provided by Blair and Schweit (2014), and discussed in the Literature Review.

b. Active Shooter Ammunition Load

For this experiment, the active shooter is limited to 500 rounds. A typical 9mm pistol round weighs 179 grains (US Army, 1994), which is approximately equal to 0.0255714 pounds (1 grain = 1/7000 pounds). Assuming an active shooter carried 500 9mm pistol rounds, this would weigh just 12.8 pounds, could be carried in a backpack, and not likely to prove a significant hindrance to movement (McDonald, 2019).

c. Active Shooter Firing Range

The active shooter's maximum firing range is 30 feet. Though this is less than the absolute maximum effective range of most pistols, it simulates the idea that the active shooter may be communicating with his intended targets (McDonald, 2019).

6. Bystander Assumptions

a. Random Initial Location within Assigned Sections

Bystanders are assigned to different sections of the building initially (as discussed Experimental Variables section below). However, within their areas of assignment, each bystander is placed randomly (McDonald, 2019).

b. Attempt to Execute Active Shooter Protocols

Bystanders attempt to execute active shooter protocols after realizing an active shooter event is taking place. These bystanders will attempt to either hide while remaining behind the nearest door, or flee to the nearest exit (McDonald, 2019).

c. Panicking

Bystanders initially exhibit random movements before executing active shooter protocols, as they run out of a room or towards someone they know (McDonald, 2019).

This helps simulate an initial onset of panic before bystanders react appropriately. Without JASPR, five to 10 percent of such individuals attempt to flee their room (and the building), while with a JASPR system, just one to two percent of such individuals attempt the same.

7. First Responder Assumptions

a. With JASPR

If a JASPR system is present during the active shooting, first responders arriving at the location "know" where the active shooter is as they are relayed information by a dispatcher/operator that can operate the cameras in the building to track the active shooter. It is also assumed that bystanders in the vicinity of the first responders supplement them with additional updates on the location of the active shooter.

b. Without JASPR

When no JASPR system is present, first responders are restricted to updates from fleeing bystanders. As a consequence of this, first responders tend to pause more often and advance to the shooter's location more slowly.

8. Agent Movement Rates

All agents initially move at 0.2 to 0.4 meters per second. However, after becoming aware of the active shooting event, agents increase their speed to 0.6 to 1.0 meters per second (McDonald, 2019).

B. EXPERIMENTAL VARIABLES

1. Independent Variables

The independent variables include three categorical factors: Active Shooter Entrance Location (with three levels), Active Shooter Suicide (yes or no), and JASPR Presence. The remaining five variables explored are: Active Shooter Firing Rate, Active Shooter Probability of Hit (p(Hit)), number of Bystanders in Cafeteria, number of Bystanders in Classrooms, and First Responder Response Time. Each variable, including its definition, range, and reasons for selection in the model are included in a small discussion below.

a. Active Shooter Entrance Location

Most of the agent-based models of active shootings discussed in the literature review, including Hayes and Hayes (2014), Briggs and Kennedy (2016), Stewart (2017), and Lee et al. (2018), do not specifically vary the active shooter's entrances. Anklam et al. (2015) is a notable exception, where the shooter is allowed to select among five entrances: three classrooms, an administrative office, and a school cafeteria. Although Anklam et al. make an admirable case for allowing CCW by the school staff or a designated first responder in their model regardless of the shooter's entry location and first shot, they do not provide any analysis on its systematic effect on casualties.

This model includes three different entrances available to the active shooter: an entrance into a large cafeteria in the middle of the model building, an entrance into a long hallway connecting multiple dorm rooms along the eastern end of the building, and an entrance into a comparatively shorter hallway connecting several classrooms along the western end of the building. The second floor of the USMAPS building used in the model and its corresponding main sections are shown by Figure 16 in the Simulation Layout sub-section of this chapter, along with different routes taken by the active shooter corresponding to each of the entrances in Figure 17, Figure 18, and Figure 19.

b. Active Shooter Suicide

Whether or not the active shooter suicided is treated as a binary factor in the design. This variable is not considered in other agent-based models, and it is likely unreasonable to include this variable in other earlier models found in the literature. Even so, Blair et al. (2014) indicated that in 44 of 104 (42.3%) active shooting events studied, the active shooter committed suicide. A shooter suicide possibility is included in this study to examine its effect on the total number of deaths and quantify how effective JASPR may or may not be when a shooter suicides.

For model runs in which the shooter suicides, the shooter is programmed to cease firing at a uniform random time between 30 seconds and the end of the run (30 minutes), after his first shot. At that time, the active shooter remains in place without firing further and awaits first responders at his location. This behavior simulates an active shooter suicide.

c. JASPR Presence

Determining how effective JASPR is at reducing the total number of deaths in the model requires examining model runs when JASPR is present and when JASPR is not present. As an experimental factor, JASPR is either enabled with all of its component systems, or it is not present at all. The placement of JASPR components was determined by subject matter experts at the JASPR program office. JASPR component placement is indicated in Figure 20.

d. Active Shooter Firing Rate

The active shooter's firing rate is varied between 45 and 60 rounds per minute (rpm). This range attempts to mirror a semi-automatic pistol, which is the typical, and most powerful, firearm used by the majority of active shooters (Blair et al., 2014). Citing a single rate of effective fire for semi-automatic weapons is problematic as sources can vary considerably depending on how the phrase "effective rate of fire" is defined. For this model, an assumption is made to accommodate a range of three rounds every four seconds (45 rounds per minute) all the way up to one round fired per second (60 rounds per minute). The shooter's firing rate does not imply that the shooter *must* fire continuously at this rate for the entire duration of every model replication. Rather, the shooter is allowed to fire up to this rate, as targets are available, within range of, and visible to, the shooter.

e. Active Shooter Probability of Hit

The active shooter's probability of hitting his target, or p(Hit), ranged between 0.25 and 0.75. Values below 0.25 are assumed to be unrealistically low, while values above 0.75 are deemed unrealistically high.

f. Bystanders in Cafeteria

The number of bystanders starting in the cafeteria varied between 10 and 240 people to simulate the ebb and flow of people filtering in and out of the cafeteria over different periods of a typical day. For example, a cafeteria is typically at its busiest during mealtimes and typically not as busy at other times. Even so, there usually are cafeteria staff moving in or around the area and occasionally a student, or groups of students, may wander through or linger. The term "victim" is intentionally not used for this variable to avoid giving the impression of any manner of physical casualty in the model. Instead, the word "bystander" is preferred for its neutral connotation.

g. Bystanders in Classrooms

Like the number of bystanders starting in the cafeteria, the number of bystanders starting in the classrooms is varied, but ranges between zero and 40 people. And much like the cafeteria, this range was selected in an attempt to model the ebb and flow of people in and out of the classrooms section of the building.

h. First Responder Response Time

Police are the typical first responders to an active shooting event, though this is not always the case, and private security or other law enforcement personnel may sometimes be in a position to respond faster. As a result, the phrase "first responder" is used as a catch-all phrase to indicate the different groups of armed responders arriving to an active shooting with intent to stop the active shooter.

First Responder Response Time ranged between zero minutes and termination of the model run at 30 minutes. However, First Responder Response Time depended on both the time required for first responders to arrive at the active shooting event as well as the time delay between the active shooting start and the time until a call is placed to a dispatcher, who then dispatches first responders. This delay is further discussed under the conditional variables.

i. Table of Independent Variables

The independent variables and their ranges, or levels if they are categorical variables, are listed in Table 1.

Table 1. Table of Independent Variables within the ABM

	Independent Variables	Minimum	Maximum	Levels (categorical)
1	AS Entrance Locations	-	-	West, Central, East
2	AS Suicide	-	-	Yes, No
3	JASPR Presence	-	-	Yes, No
4	AS Firing Rate	45 rnds/min	60 rnds/min	-
5	AS Probability of hit	0.25	0.75	-
6	Bystanders in Cafeteria	10 people	240 people	-
7	Bystanders in Classrooms	0 people	40 people	-
8	First Responder Response Time	0 min	30 min	-

2. Conditional Variables and Response of Interest

The remaining variables included in the ABM are the number of bystanders located in the dorm rooms, the cognitive delay for bystanders to recognize that an active shooter is in the area, and the time required to dispatch first responders to the area. These variables are considered conditional variables (i.e., variables that are conditionally dependent on one or more of the independent variables). And, while they varied during execution of the model, these are not systematically varied via the experimental design described in Section B.

a. Bystanders in Dorm Rooms

Bystanders in dorm rooms is defined as 340 bystanders (the maximum possible) minus the sum of the number of bystanders assigned to the classrooms and the cafeteria. This is intended to capture the movement of bystanders between different parts of the building throughout a normal day, reducing the number of bystanders loitering in their dorm rooms and increasing their numbers in other sections of the building, as is normally the case. This also allows a straightforward comparison of Total Deaths across the potential bystander locations.

b. Cognitive Delay + Dispatch Time

Cognitive delay + dispatch time is defined as the time delay between bystander realization of an active shooting event until the time a dispatcher notifies first responders that an active shooting is in progress. None of the surveyed literature indicated what a realistic cognitive delay might be during an active shooting, especially coupled with the time required for a dispatcher to ascertain the active shooting location from a stressed bystander. Instead, an assumption is made that when JASPR is not present, the cognitive delay varies according to a uniform random variable with a minimum of zero and maximum of 30 seconds, and the dispatch delay follows a uniform random variable with minimum of zero and maximum of 60 seconds. When JASPR is present, it is assumed that there is no (zero) cognitive delay, since a gunshot detector is designed to immediately detect the sound of the active shooter's gunshots, electronically notify the local dispatcher, and render the cognitive delay irrelevant. However, even with JASPR, the dispatch delay remained uniformly from 0 to 60 seconds, as this is a function of the call center procedures and responsiveness, and not the presence of a JASPR system.

c. Total Deaths

Total Deaths, the main response of interest in this study, is defined as the final tally of bystander deaths at the end of each replication. The response has a lower bound of zero (no deaths) and an upper bound of 340 (maximum number of bystanders).

***d.* Table of Conditional Variables**

The dependent variables and their ranges are listed in Table 2, alongside a description of their functions.

Table 2. Table of Conditional Variables within the ABM

	Dependent Variables	Minimum	Maximum	Descriptive Function
1	Bystanders in Dorm Rooms	65 people	325 people	Bystanders in dorms = 340 - (Cafeteria + Classrooms)
2	Cognitive Delay + Dispatch Time	0	90 seconds	Cognitive Delay = 0 if JASPR Present, U ~ (0,30) (secs) otherwise, Dispatch Time = U ~ (0, 60) (secs)

C. DESIGN OF EXPERIMENTS

The independent variables described in the previous section are systematically varied via an efficient design of experiment (DOE).

A full factorial design is used for the three categorical variables. The full factorial design accounts for all combinations of the three levels corresponding to the Active Shooter Entrance Locations (classrooms, cafeteria, dorm rooms), the two levels for JASPR Presence (Yes or No), and the two levels for Active Shooter Suicide (Yes or No). This yields 12 ($3 \times 2 \times 2$) design points (DPs).

A 125 DP second order Nearly Orthogonal Latin Hypercube (NOLH) (MacCalman et al., 2017) samples across the remaining numerical variables. The use of the second order NOLH allows for an efficient and space-filling exploration of the design space, with negligible multicollinearity among input factors and their second order effects, and allows for flexible analysis goals. Additionally, the second order NOLH provides excellent space-filling properties that enables the detection of model bias in the presence of step functions (MacCalman et al., 2017).

Crossing the 12 DPs from the full factorial for the categorical variables with the 125 DPs from the second order NOLH, yields 1,500 DPs (12×125). 30 independent replications are conducted at each DP, yielding 45,000 active shooter simulations across all independent variables. Each replication of the ABM produced a time series of deaths as well as a cumulative total. To keep file sizes manageable, deaths are reported once every 10 time steps instead of every time step.

A scatterplot matrix, shown in Figure 21, shows the near-orthogonality of the independent numeric variables with respect to each other and the space-filling properties of the second order NOLH.

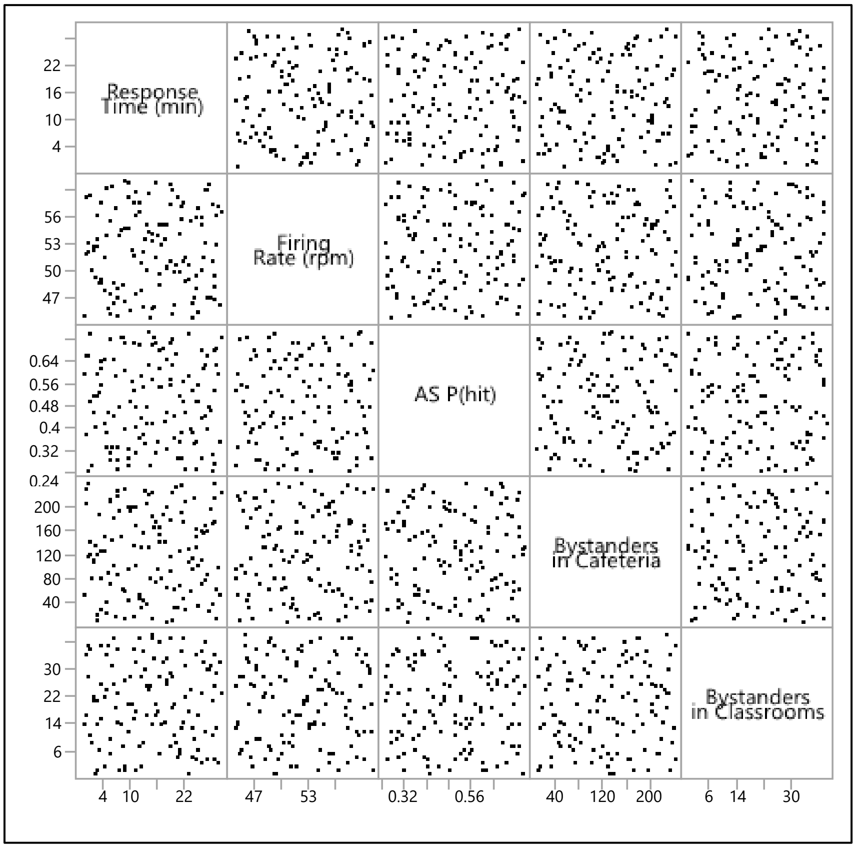

Figure 21. Scatterplot Matrix for Numeric Independent Variables

Figure 22 displays the corresponding correlation matrix for these independent variables. The correlation matrix confirms the nearly orthogonal design of the experiment, indicating correlations near zero for each pair of variables.

	Response.Time (min)	Firing.Rate (rpm)	AS P(hit)	Bystanders in Dining	Bystanders in Classrooms
Response.Time (min)	1.0000	0.0014	-0.0003	0.0064	-0.0005
Firing.Rate (rpm)	0.0014	1.0000	-0.0002	0.0019	0.0049
AS P(hit)	-0.0003	-0.0002	1.0000	0.0040	0.0156
Bystanders in Dining	0.0064	0.0019	0.0040	1.0000	0.0181
Bystanders in Classrooms	-0.0005	0.0049	0.0156	0.0181	1.0000

Figure 22. Correlation Matrix of Independent Variables.

D. MODELING AND ANALYSIS SOFTWARE

1. ABM Software—Pythagoras

Pythagoras is the government-owned, stochastic, time step ABM environment used to create the base model for both this thesis and the preceding research done by McDonald (2019) for the JASPR Office. Pythagoras was originally developed by Northrop Grumman for the U.S. Marine Corps as a medium resolution ABM software and, as such, is primarily designed for military modeling. For example, Pythagoras has been applied in the past to model how unmanned surface vehicles might perform in force protection missions (Cioppa et al., 2004).

However, Pythagoras is easily adaptable for simulating active shooter incidents, and easily lends itself to modeling terrain, along with agent behavior, agent movement, agent resources, agent attributes, and interaction and communication among individual agents across different time steps. Pythagoras is also capable of modeling the effect of different weapon characteristics.

Further details and possibilities for similar applications with Pythagoras can be found in Cioppa et al. (2004) and Henscheid et al. (2006).

2. Analytical Software—JMP

JMP is a statistical software package originally developed by SAS. JMP stores data in a spreadsheet like format which easily allows users to launch data visualization and analysis tools around the data. The visualization and analysis tools in JMP are intuitively created and adjusted, and the software allows for application of both routine and advanced statistical techniques, yet requires little-to-no programming. JMP Pro version 14.2 is used to perform the bulk of the analysis presented in next chapter.

JMP is commercial software, requiring a paid license to use. JMP is also capable of taking advantage of several statistics packages found among the R and Python programming languages. Additionally, JMP can be operated on both Windows-based and Mac computers. Further JMP information can be obtained at the company's website: https://www.jmp.com/en_us/home.html.

E. VARIABILITY FOR A REPRESENTATIVE "BASE" CASE

A base case for Total Deaths is illustrated here. The base case demonstrates the stochastic nature of the model and suggests the role that randomness plays in the main response for a specific set of circumstances. In the base case, no JASPR system is present, the Active Shooter Entrance Location is set to a dorm room entrance, First Responder Response Time is set to 20 minutes, and the active shooter does not suicide during his rampage. Total Deaths are recorded for each of 100 model runs and summarized in the histogram and boxplot shown in Figure 23.

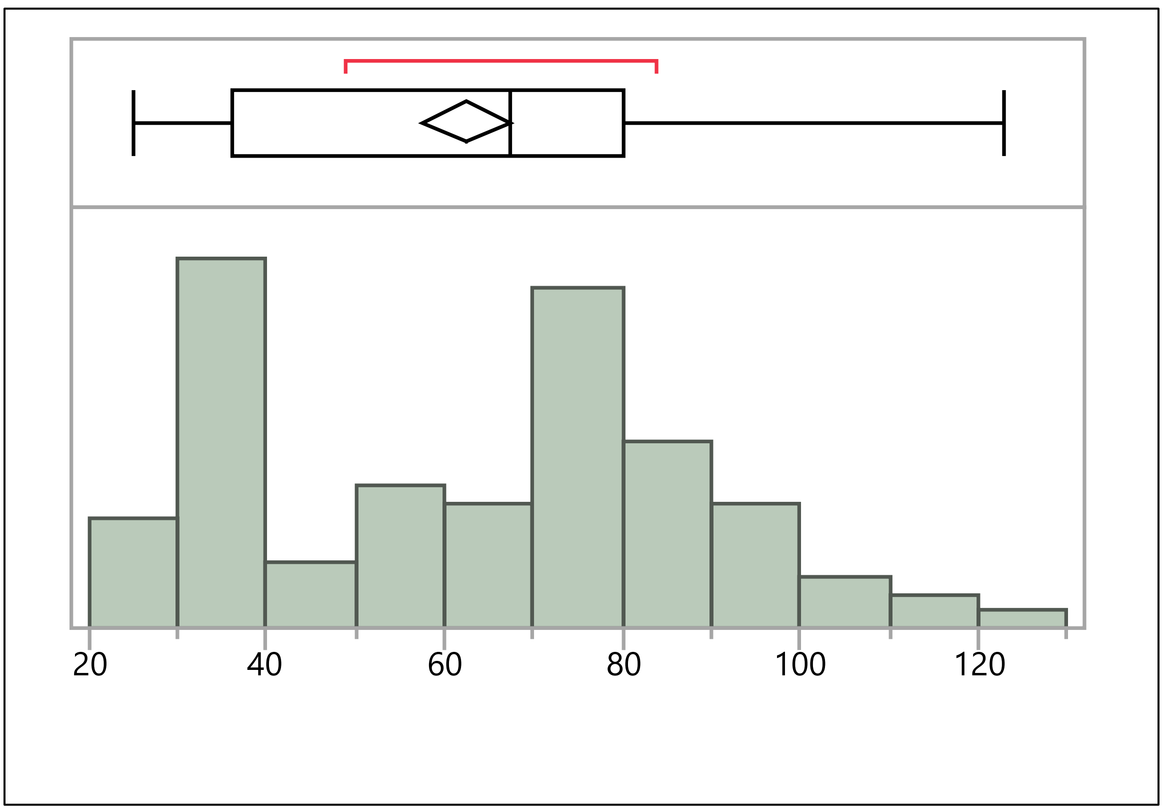

Figure 23. Total Deaths Inflicted by Active Shooter: No JASPR, Dorm Room Entrance, No Suicide, 20-Minute Response Time

The histogram is bimodal: there are typically a range of Total Deaths between 30 and 40, or else, a range of Total Deaths between 70 and 80. The random draws governing speed of communication or the presence of an active shooter and the effectiveness of the attempted lock-down procedures likely drove the difference between the bad and worse modes. The mean and median fall between the two modes and suggest measures of central tendency for Total Deaths at 62.5 or 67.5, respectively. A table of quantiles for the base case is shown in Table 3, providing further details on the distribution of Total Deaths. Table 4 offers additional summary statistics.

Table 3. Base Case Quantiles

100.0%	maximum	123
99.5%		123
97.5%		112.425
90.0%		92.9
75.0%	quartile	80
50.0%	median	67.5
25.0%	quartile	36
10.0%		31
2.5%		27.525
0.5%		25
0.0%	minimum	25

Table 4. Base Case Summary Statistics

Mean	62.53
Std Dev	24.79
Std Err Mean	2.48
Upper 95% Mean	67.45
Lower 95% Mean	57.61
N	100

V. RESULTS AND ANALYSIS

A. EXPLORATORY DATA ANALYSIS

An initial examination of the relationships between conditional and independent variables and the main response is displayed via a scatterplot matrix in Figure 24. The main response, Total Deaths, appears at the bottom left in red text and the two dependent variables, Bystanders in Dorm Rooms and Cognitive Delay + Dispatch Time, are noted in blue text.

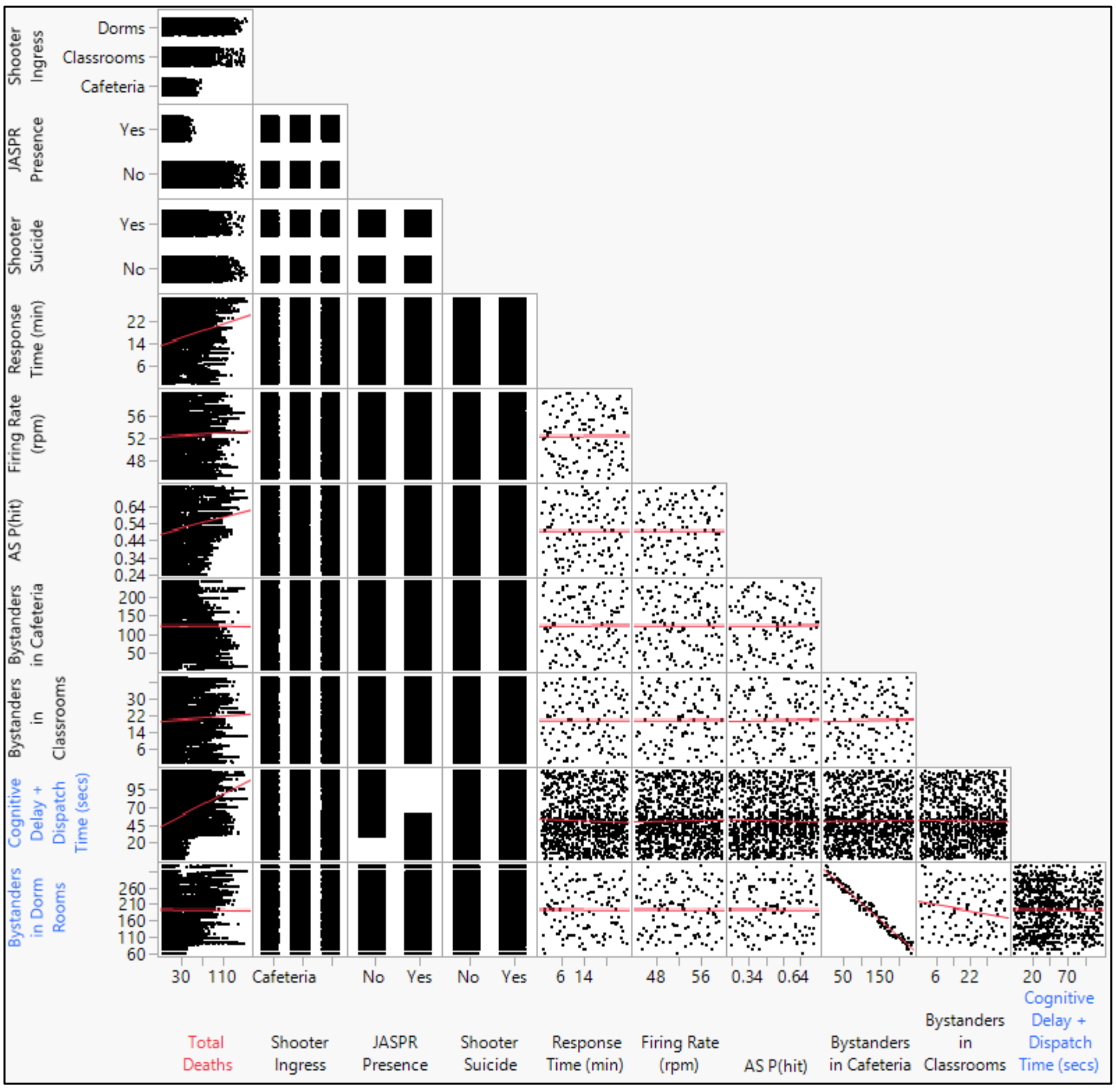

Figure 24. Scatterplot Matrix of Independent and Conditional Variables

The red lines indicate a standard least-squares linear fit for each of the numeric-to-numeric variable relationships. As intended, the linear fit between independent numeric variables demonstrates the effect of the second order NOLH: virtually zero correlation between them. By virtue of the design, significant collinearity effects are avoided between the experiment factors and their second order terms (not displayed in Figure 24).

Also seen at first glance are how the independent variables affect Total Deaths along the far left set of scatterplots. A few strong relationships are apparent, and these are explored in further detail in the subsequent sections.

B. UNIVARIATE ANALYSIS OF TOTAL DEATHS

As the response of interest for this study, Total Deaths ranges from zero to 164, is unimodal with a mode of three, has mean of 17.6, median of eight, and is right skewed. The histogram in Figure 25 reflects the low mode and positive skew for Total Deaths over the 45,000 simulated active shooter incidents.

These statistics suggest the relatively infrequent occurrence of extremely high numbers for Total Deaths, regardless of the impact of the other variables. The median indicates that runs with eight or fewer deaths are just as likely as model runs with more than eight deaths. The histogram further suggests that a larger number of deaths is relatively unlikely.

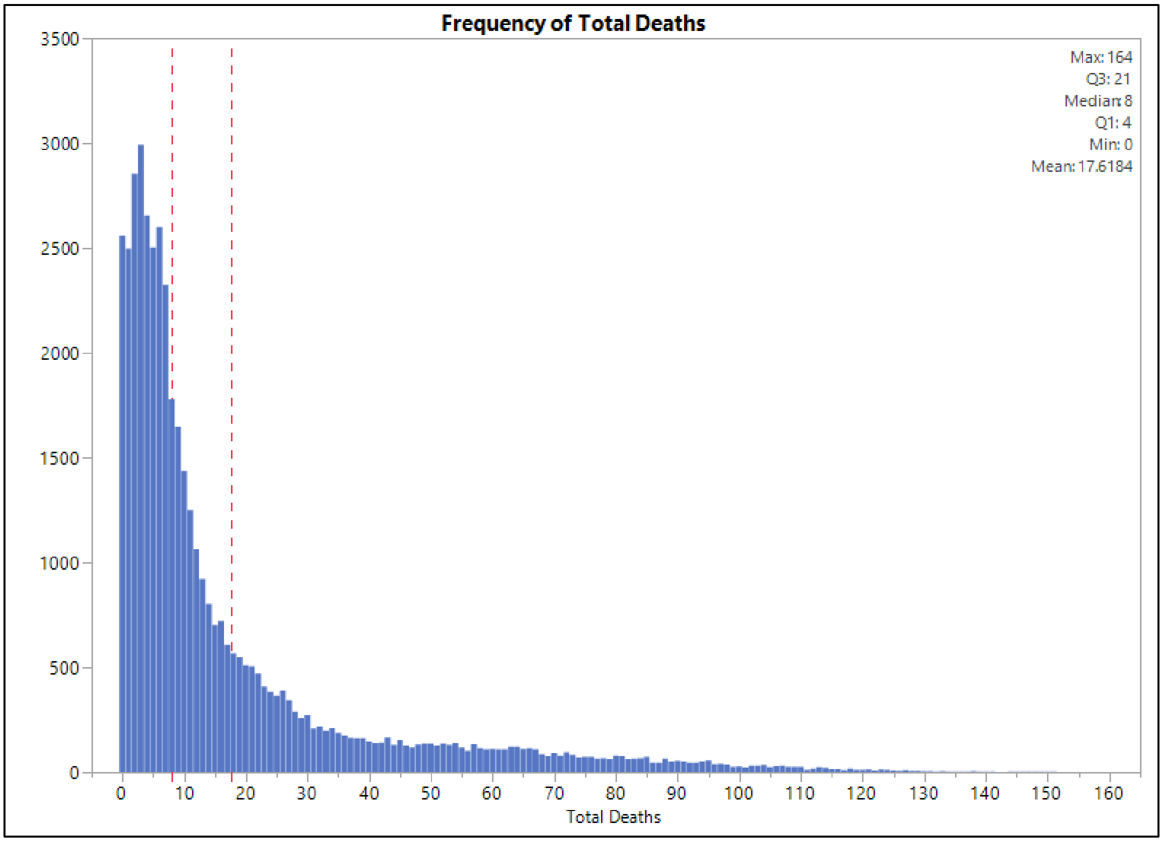

Figure 25. Total Deaths Across all Independent Variables

C. BIVARIATE ANALYSIS OF TOTAL DEATHS VERSUS INDEPENDENT VARIABLES

As the response of interest, Total Deaths is examined against the independent variables. First, the three categorical variables, Active Shooter Entrance Location, JASPR Presence, and Active Shooter Suicide are examined and compared with respect to Total Deaths. Then, two of the numeric variables, First Responder Response Time and the Active Shooter p(Hit), are investigated to quantify their impact on the mean of Total Deaths. Because the scatterplot matrix in Figure 24 indicates that Active Shooter Firing Rate, Bystanders in Cafeteria, and Bystanders in Classrooms did not have a large individual impact on Total Deaths, and because they are considered again in the multivariate analysis, we do not present their bivariate fits in this section.

For categorical variables, boxplots for each level are used to show the difference in response while scatterplots display the mean of Total Deaths versus the numeric variables. Displaying mean Total Deaths over a design point's replications rather than displaying all Total Deaths for each of the 45,000 model runs avoids cluttering the scatterplots and indicates a more cleanly discernible trend in the response.

1. Total Deaths versus Active Shooter Entrance Location

The greatest number of deaths typically occurred when the active shooter entered the cafeteria section of the building and opened fire, with a corresponding median of 14. Likewise, there are typically fewer deaths, with median of five, when the active shooter entered the classroom section of the building. However, the active shooter's selection of the classrooms also presented, by far, the most outliers and the greatest maximum deaths at 164 versus just 73 and 156 for the cafeteria and dorm room entrances, respectively. In contrast, the dorm room entrance held the largest count of Total Deaths at the 75th percentile (Q3), but the fewest outliers compared to the previous entrances.

Figure 26 displays three different boxplots reflecting the differences in Total Deaths that correspond with each of the three Active Shooter Entrance Locations. They show dramatic, and slightly unexpected, differences in Total Deaths by location. The boxplots are color coded blue, green and purple, to align with the cafeteria, classroom, and dorm room section shading for the building map in Figures 16, 17, and 18 from the Methodology chapter; outliers are jittered for each boxplot. The upper right corner associated with each boxplot contains a five-number summary for Total Deaths by location.

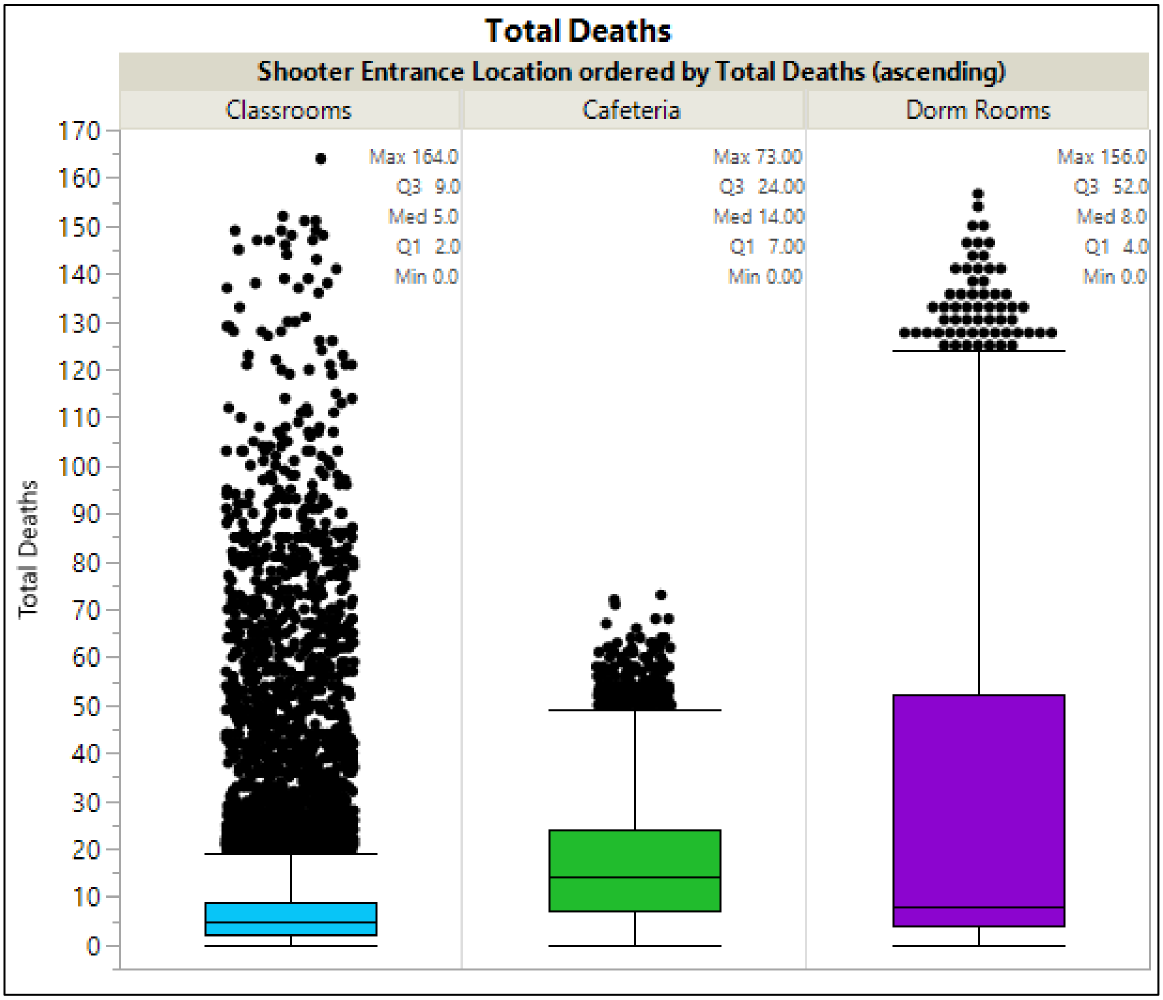

Figure 26. Total Deaths by Active Shooter Entrance Location (Classrooms, Cafeteria, Dorm Rooms)

2. Total Deaths versus Active Shooter Suicide

Total Deaths is also influenced heavily by Active Shooter Suicide after the active shooter's first shot is fired. Again, the active shooter committed suicide according to a uniform random variable between zero and 30 minutes after the time of the first shot. Unsurprisingly, there are fewer deaths when the active shooter commits suicide under this assumption. Figure 27 quantifies this with a median number of deaths at five when the active shooter suicided compared to 13 when the active shooter does not.

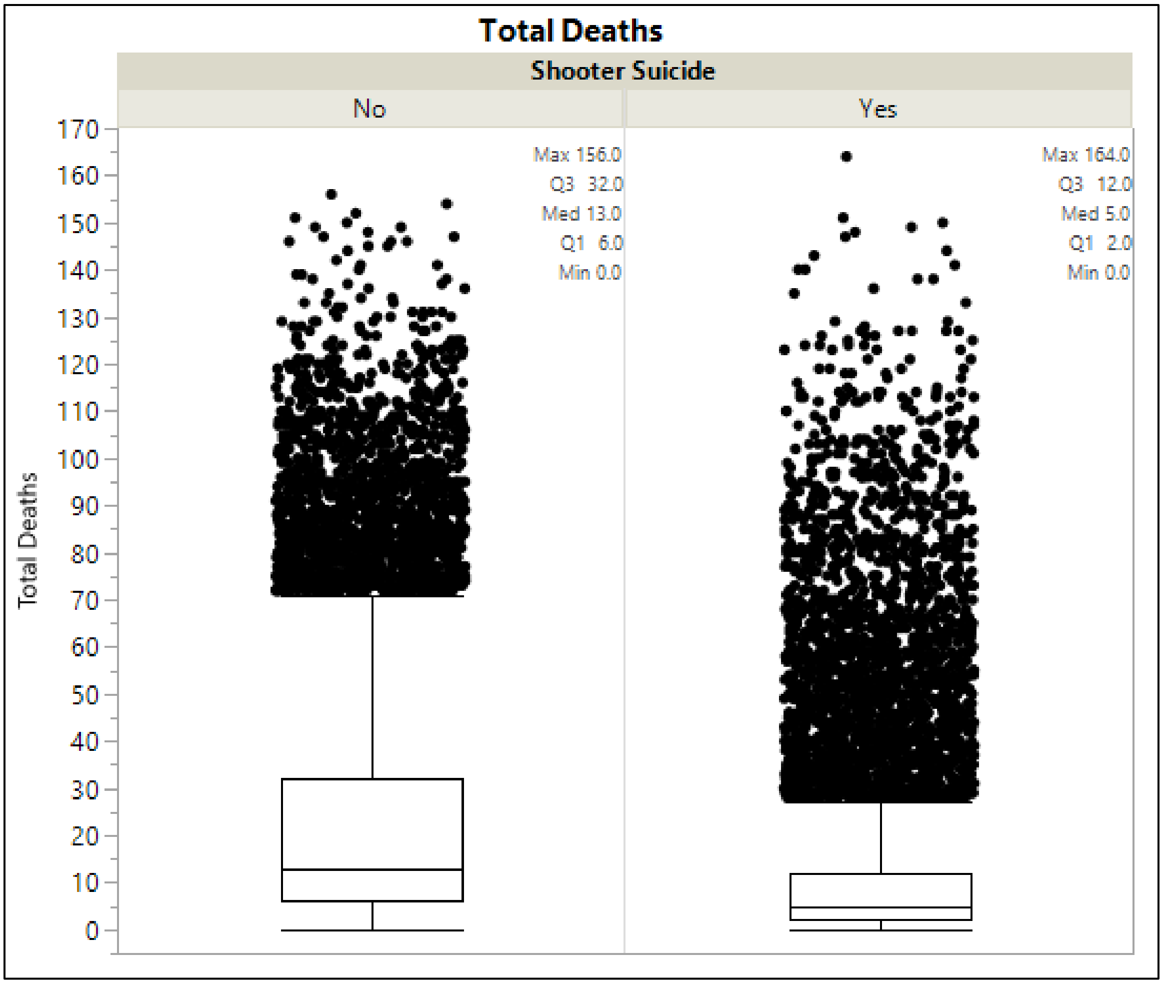

Figure 27. Total Deaths by Active Shooter Suicide

Additionally, both sets of data show relatively different theoretical upper limits or top whiskers (i.e., the median + 1.5 × the interquartile range [IQR]); scenarios without AS suicides have a maximum of 71, while scenarios with AS suicides have a maximum of 27, before observations are classified as outliers. While outlier classification is not necessarily of direct interest because the underlying data is highly skewed, the differences in IQR show variability in Total Deaths is substantially lower in scenarios with Active Shooter Suicide.

3. Total Deaths versus JASPR Presence

Figure 28 indicates Total Deaths by JASPR Presence with two boxplots and jittered outliers and quartiles at the top right for each plot. The boxplots show a clear difference in outcomes here, with fewer Total Deaths when JASPR is present. This result suggests a direct answer to the main research question on whether JASPR is, in fact, effective at reducing deaths.

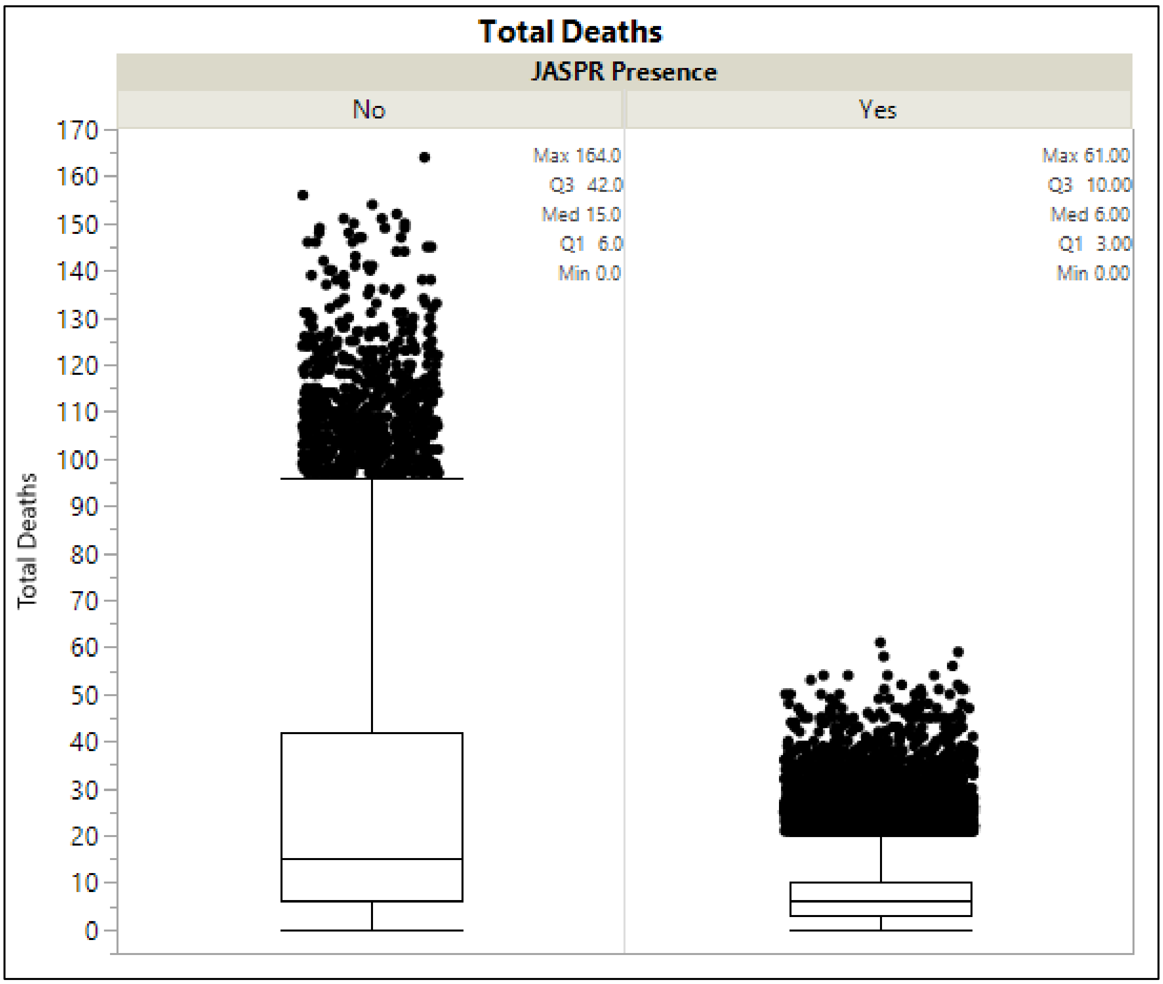

Figure 28. Total Deaths by JASPR Presence (Yes or No)

When JASPR is present, three deaths, six deaths, and 10 deaths occurred at Q1, Q2, and Q3, respectively; while six, 15 and 42 deaths occurred at Q1, Q2, and Q3, respectively, when JASPR is not.

4. Mean Total Deaths versus Active Shooter p(Hit)

The Exploratory Data Analysis section's scatterplot (Figure 24) suggests a moderate-to-strong relationship between mean Total Deaths and Active Shooter p(Hit) in the presence of all the other input factors. A quadratic regression is fit as it provides a better fit than a linear regression and helps quantify the relationship between the variables. The concavity of the fit indicates that as the active shooter's p(Hit) increases, mean Total Deaths increases, though the increases to mean Total Deaths are marginally decreasing. Figure 29 shows this regression against a scatterplot of mean Total Deaths and Active Shooter p(Hit), coupled with its equation, root mean squared error, and its R^2 value in the upper left; the shaded blue area indicates its 95% confidence interval around the regression.

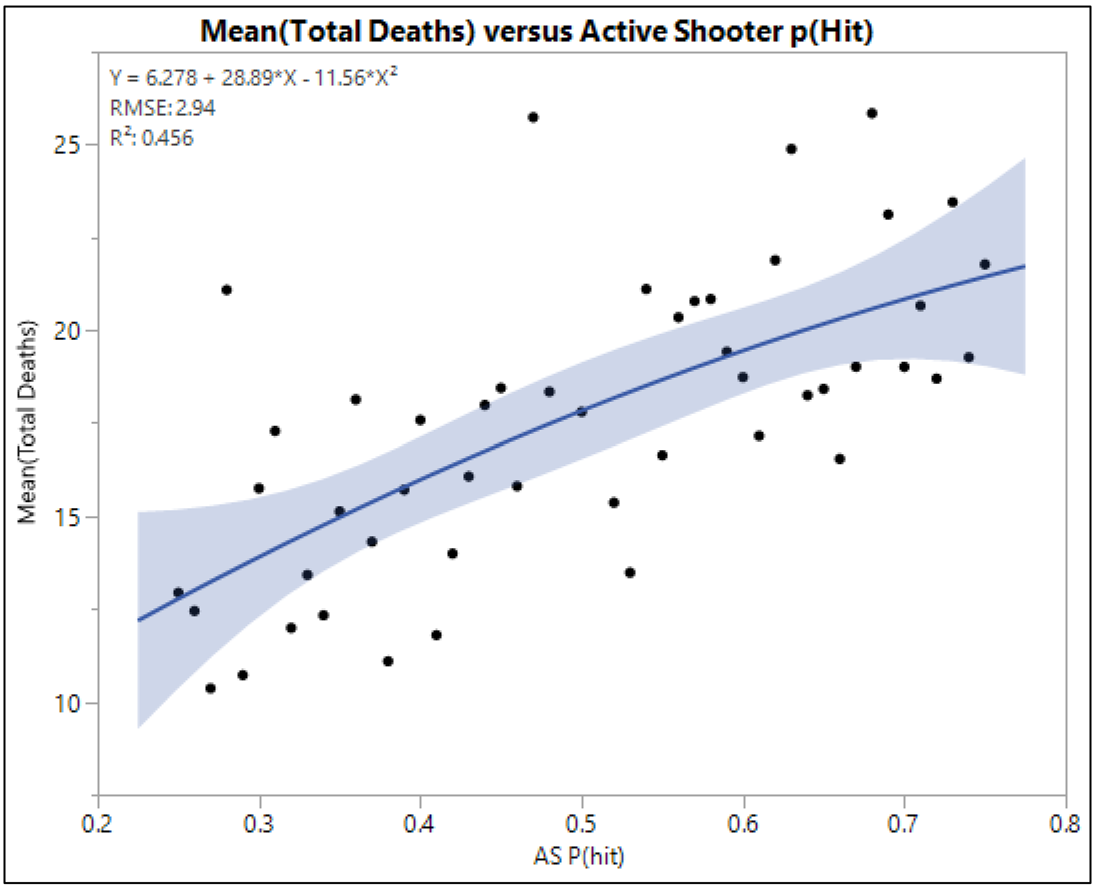

Figure 29. Mean Total Deaths versus Active Shooter p(Hit)

5. Mean Total Deaths versus First Responder Response Time

Like mean Total Deaths and Active Shooter p(Hit), the Exploratory Data Analysis section's scatterplot (Figure 24) suggests a moderate-to-strong relationship between mean Total Deaths and First Responder Response Time while all other factors are varying. A cubic, rather than quadratic, regression is selected to fit the data points here and capture the comparatively sharper increase in mean Total Deaths in the first few minutes of response time, the leveling off of mean Total Deaths afterward, and then the acceleration of mean Total Deaths as First Responder Response Time increases further. Figure 30 displays a scatterplot of mean Total Deaths across First Responder Response Times, along with the cubic regression equation, root mean squared error and the regression R^2 in the upper left; the 95% confidence interval for the regression is shown by the shaded blue area.

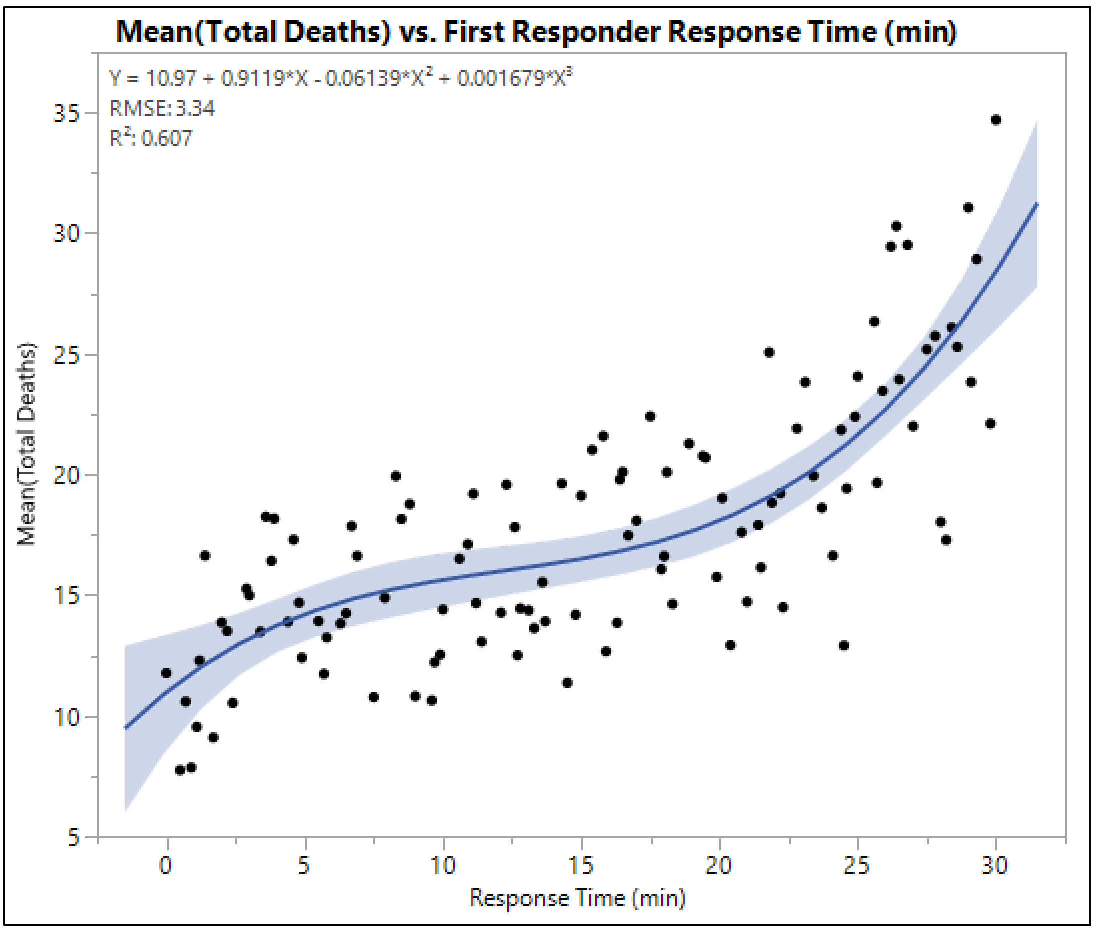

Figure 30. Mean Total Deaths versus First Responder Response Time

The graph suggests that an inflection point occurs just past 12 minutes, implying that as the First Responder Response Time lags beyond this time, the average number of deaths during model runs tends to become exponentially greater.

D. MULTIVARIATE ANALYSIS OF TOTAL DEATHS VERSUS INDEPENDENT VARIABLES

1. Estimating Mean Total Deaths with Stepwise Regression

A stepwise regression analysis of the independent variables is run to show the effect of each variable, or combination of variables, on mean Total Deaths. All main effects, two-way interactions, quadratic terms, three-way interactions, and cubic terms were eligible for inclusion in the stepwise model. The initial regression model fit shows that a square root transformation of the response variable makes the residual variance more homogenous. The stepwise regression in Figure 31 indicates this transformation with the regression line in red, coupled with a 95% confidence interval in the shaded red area. The square root of Mean Total Deaths at each DP is indicated by a point and a horizontal blue line indicates the overall mean, regardless of DP, at approximately the 3.71 deaths$^{0.5}$.

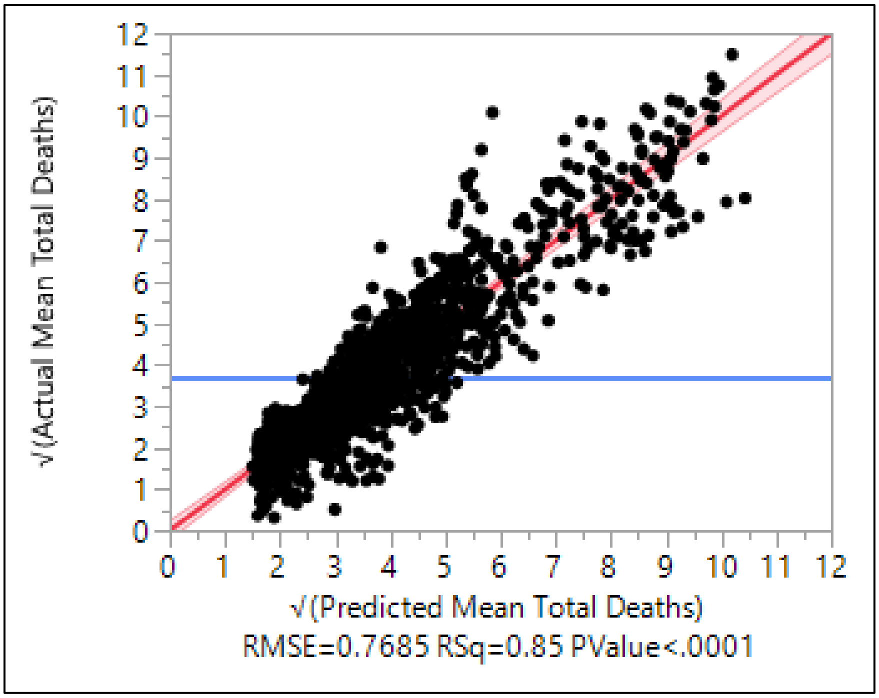

Figure 31. Actual versus Predicted Square Root of Mean Total Deaths

The regression residuals for the square root transformation of mean Total Deaths shows roughly equal variance across predicted values in Figure 32.

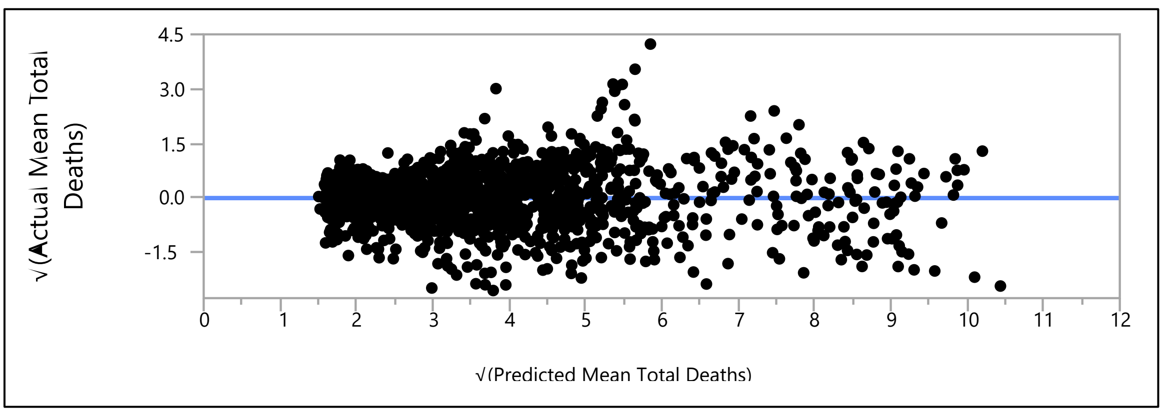

Figure 32. Residual Plot for Square Root of Mean Total Death Regression

However, a normal quantile plot of the regression's residuals, shown in Figure 33, suggests that the residuals approach, but fail to achieve, a normal distribution, due to their heavily tails. Dashed red lines indicate the Lilliefors confidence bounds for normality

(Lilliefors, 1967). This means that the p-values for tests of significance in the regression are not precise.

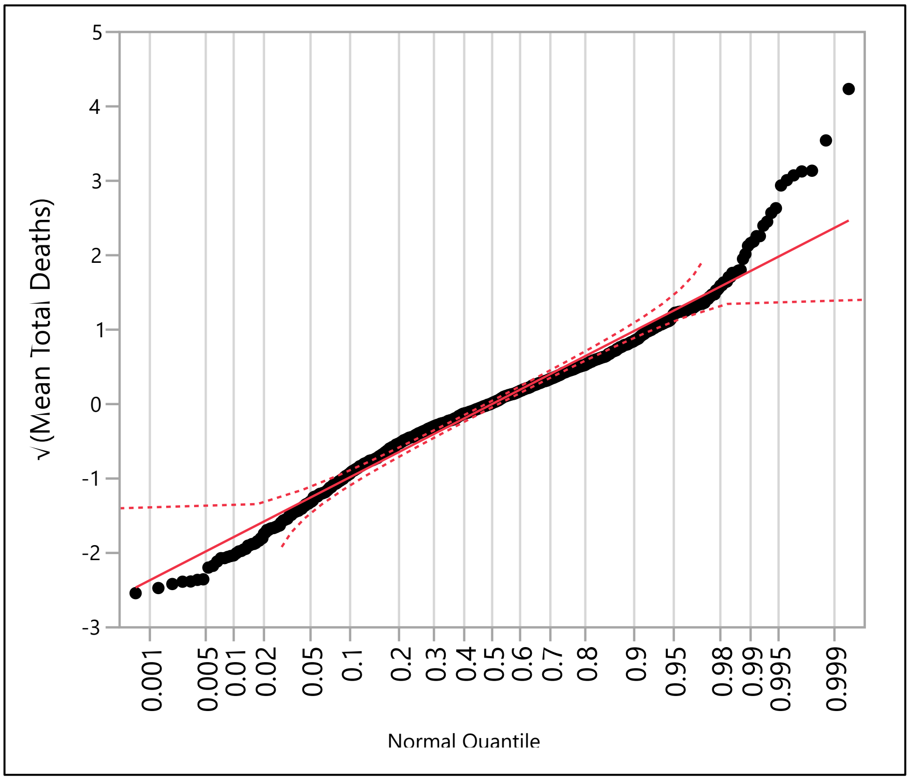

Figure 33. QQ-Plot for √(Mean Total Deaths)

The regression attained an adjusted R^2 value of 0.846, captured in Table 5, meaning that the regression explains nearly 85% of the variability of the summarized data.

Table 5. Stepwise Regression—Summary of Fit Statistics.

Statistic	Value
R^2	0.848
R^2 Adjusted	0.846
Root Mean Square Error	0.768
Mean of Response	3.712
Observations	1500

Table 6 lists the terms included by the stepwise regression in decreasing order of importance. Several key insights may be gleaned from this list of terms: First, JASPR Presence is identified as the factor with the highest t ratio, indicating that it is the most statistically significant predictor of mean Total Deaths throughout the model. Second, Active Shooter Entrance ("Shooter Ingress" in Table 6) has the next highest impact. Active Shooter suicide, then the model's first interaction, between the cafeteria entrance and JASPR Presence, are the next most influential. The stepwise regression includes only two of the numeric variables, First Responder Response Time and Active Shooter p(Hit), reinforcing the results previously seen in the scatterplot matrix from Figure 24. In fact, the first numeric variable identified by the regression as significant is First Responder Response Time ("Response Time" in Table 6), fifth in the list of sorted parameter estimates.

Table 6. Stepwise Regression—Parameter Estimates (Sorted)

Term	Estimate	Std Error	t Ratio	Prob>|t|
JASPR Presence [No]	1.0337292	0.019842	52.10	<.0001*
Shooter Ingress [Classrooms]	-0.945328	0.028061	-33.69	<.0001*
Shooter Suicide [No]	0.6331359	0.019842	31.91	<.0001*
Shooter Ingress [Dining]*JASPR Presence [No]	-0.81703	0.028061	-29.12	<.0001*
Response Time (min)	0.0507541	0.002275	22.31	<.0001*
JASPR Presence [No]*Shooter Suicide [No]	0.3461098	0.019842	17.44	<.0001*
AS P(hit)	1.9385093	0.135834	14.27	<.0001*
Shooter Ingress [Classrooms]*JASPR Presence [No]	-0.326551	0.028061	-11.64	<.0001*
JASPR Presence [No]*(Response Time (min)-15.008)	0.0232239	0.002275	10.21	<.0001*
Shooter Ingress [Dining]*JASPR Presence [No]*Shooter Suicide [No]	-0.261759	0.028061	-9.33	<.0001*
Shooter Suicide [No]*(Response Time (min)-15.008)	0.0168615	0.002275	7.41	<.0001*
Shooter Ingress [Dining]	0.180361	0.028061	6.43	<.0001*
Shooter Ingress [Classrooms]*(AS p(Hit)-0.49992)	-1.152506	0.192098	-6.00	<.0001*
JASPR Presence [No]*(AS P(hit)-0.49992)	0.6799759	0.135834	5.01	<.0001*
Shooter Ingress [Dining]*(AS p(Hit)-0.49992)	0.87602	0.192098	4.56	<.0001*
Shooter Ingress [Classrooms]*JASPR Presence [No]*Shooter Suicide [No]	-0.110631	0.028061	-3.94	<.0001*
Shooter Ingress [Classrooms]*Shooter Suicide [No]	-0.109668	0.028061	-3.91	<.0001*
Shooter Ingress [Dining]*JASPR Presence [No]*(AS p(Hit)-0.49992)	-0.613127	0.192098	-3.19	0.0014*
Shooter Ingress [Dining]*Shooter Suicide [No]	-0.070031	0.028061	-2.50	0.0127*
Shooter Ingress [Classrooms]*JASPR Presence [No]*(AS p(Hit)-0.49992)	-0.351891	0.192098	-1.83	0.0672

JMP also offers a prediction profile tool, illustrated in Figure 34, indicating how each of the main effects from the stepwise regression affects the mean Total Deaths response. The prediction profile's vertical cross-hairs align with different values for each of the included variables, while the horizontal cross-hairs provide the mean for Total Deaths at those settings of the included variables.

The prediction profile shows how JASPR Presence and Active Shooter Suicide clearly decrease mean Total Deaths, while First Responder Response Time and Active Shooter p(Hit) increase mean Total Deaths over their respective ranges. We also see that Active Shooter Entrance has a dramatic effect on mean Total Deaths and dorm room entry is associated with the highest death count.

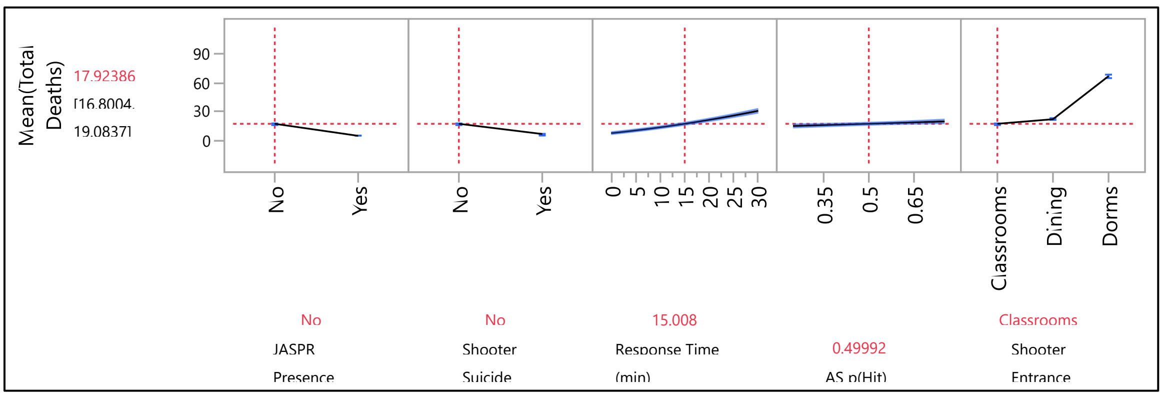

Figure 34. JMP Prediction Profile for the Regression on Mean Total Deaths

Additionally, Figure 35 displays the set of interaction profiles for each of the two-way interactions in the regression model. The presence of non-parallel lines is a visual indicator of an interaction between two variables, meaning that the effect of one variable depends on the value of the variable it is interacting with. For example, one of the stronger interactions, the interaction between JASPR Presence and Response Time, is visually captured with either the first row, third column (or with the third row, first column—these are complementary). When JASPR is present (blue line), then the response time does not have a strong impact on deaths, but when JASPR is not present (red line), then longer response times dramatically increase Total Deaths.

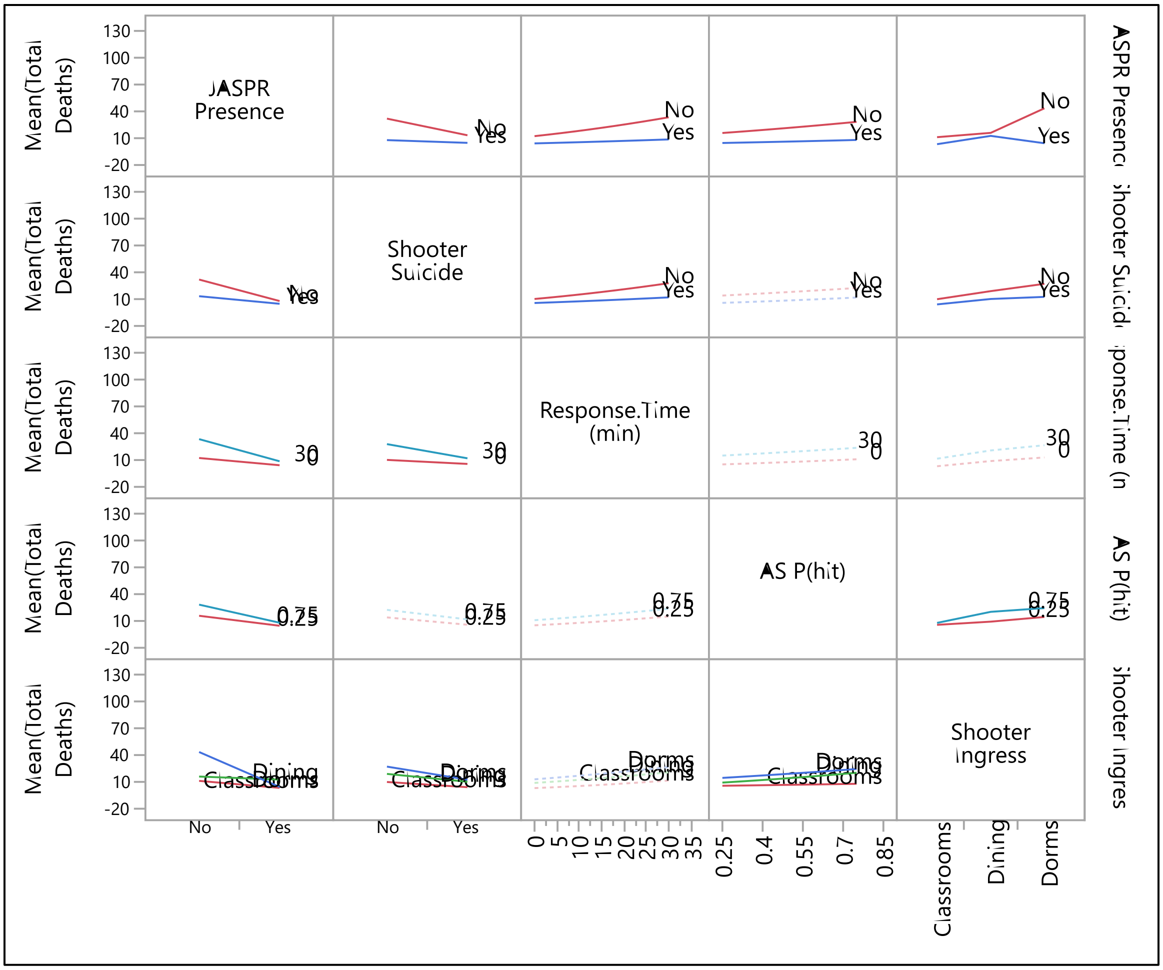

Figure 35. Interactions between Independent Variables

Similarly, JASPR Presence and Active Shooter Entrance Location (first row, fifth column) is identified by the stepwise regression as the strongest of the interaction effects. The disparity between mean Total Deaths depending on entrance location and JASPR Presence is stark, with the dorm room entrance showing the largest difference in deaths between with and without JASPR.

2. Estimating Mean Total Deaths with a Partition Tree

Next, a partition tree was fit, to capture the relationships between independent variables and the response. Partition trees are generally considered to complement the results obtainable by regression because they are nonparametric, are capable of capturing jumps in the response, interaction arise naturally, and display results in an intuitive easy-to-understand form. The most impactful independent variables in a decision tree are generally nested higher, while the less important variables are nested lower.

A relatively compact tree with high explanatory power across five splits (or branches) is displayed in Figure 36. The tree was constructed using cross-validation and yielded a final R^2 value of 0.74. While every additional split in a partition tree generally increases the tree's explanatory power, with each split, the possibility of overfitting the tree to the data increases.

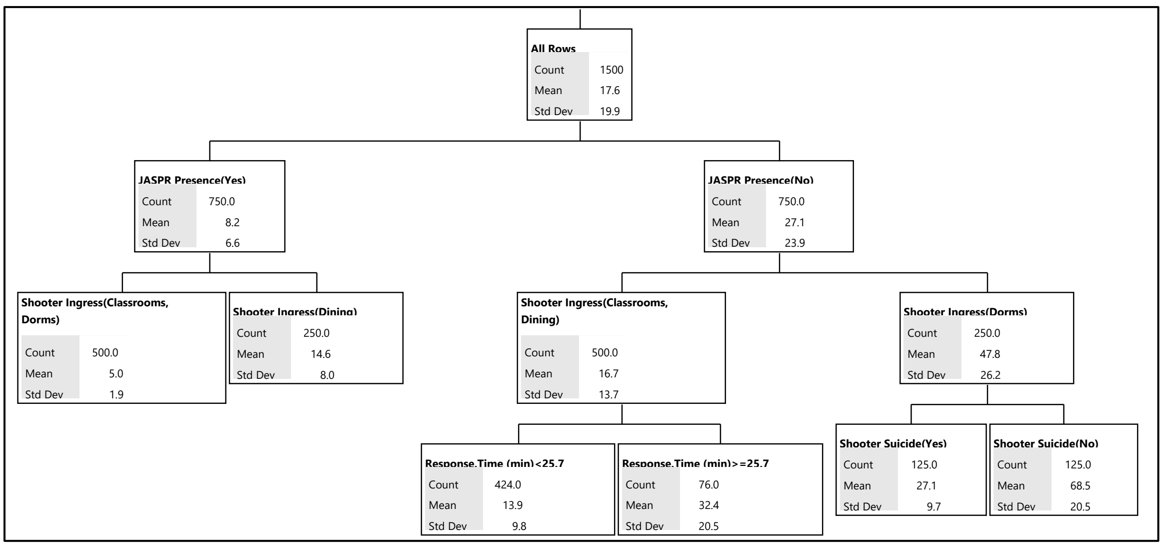

Figure 36. Partition Tree for Mean Total Deaths

A few performance metrics for this partition tree, including R^2, RMSE, the total number of observations or DPs (N), number of splits, and Akaike Information Criterion (AICc) are captured in Table 7.

Table 7. Decision Tree—Metrics on Five Splits.

R^2	RMSE	N	Number of Splits	AICc
0.741	10.12	1500	5	11,215

With every split of the data by the partition tree, the tree's R^2 increases, though the tree experiences diminishing returns to this statistic after the fourth split. Assuming splits of the tree continued, the tree's marginally increasing R^2 is shown in Figure 37.

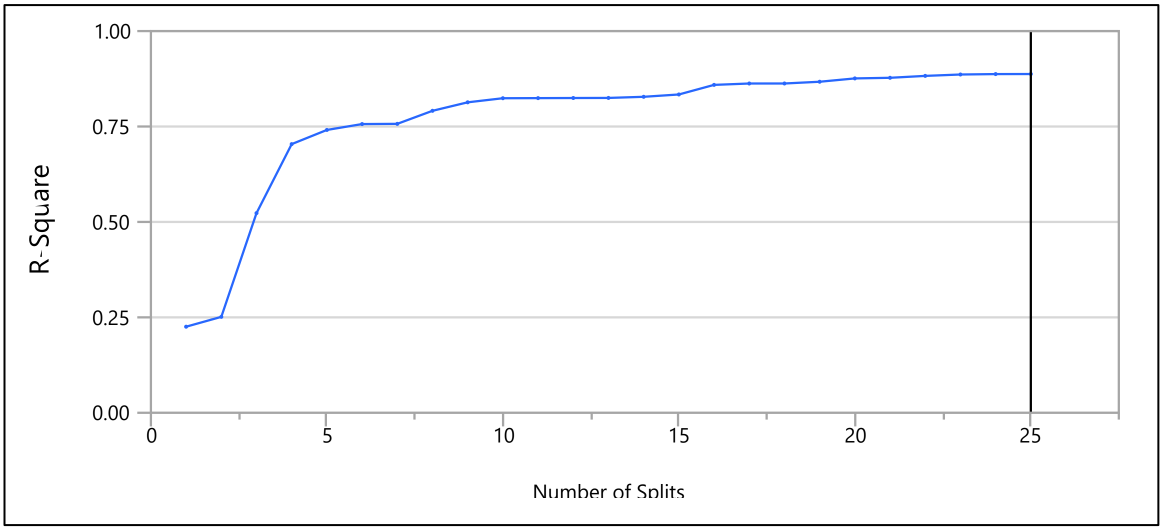

Figure 37. Partition Tree Split History by R^2

The partition tree complements and generally confirms the results of the regression, with respect to the most critical variables. JASPR Presence, followed by Active Shooter Entrance Location, Active Shooter Suicide, and then First Responder Response Times are the most impactful variables overall. The interpretation of the first split is that for the 750 cases in which JASPR is present, there are 8.2 deaths on average, but for the 750 cases in which JASPR is not present, the average deaths jumped to 27.1. At each split, the algorithm seeks to split on the factor and split point that separates the data as much as possible with respect to mean Total Deaths.

The tree shows that the difference in mean Total Deaths is relatively large: there are just 4.9 mean Total Deaths in a best-case scenario (lower left leaf) with JASPR Presence and the active shooter enters into either the classrooms or dorm rooms, while in a worst-case scenario (lower right leaf) there are an average of 68.5 Total Deaths without JASPR Presence and the active shooter enters the dorm rooms and fails to suicide.

3. Random Forest Analysis

Since the partition tree method is greedy, can be particularly sensitive to the underlying data, and can fail to capture some important relationships, it is useful to run a random forest of individual partition trees. Running a bootstrapped random forest of 100 (or more) decision trees, and averaging results across them, provides a more robust method for ranking the independent variables by contribution to Total Deaths. The result of the random forest performed is shown in Table 8. The figure displays each of the independent variables under the "Predictor" column, a "Contribution" column indicating the total amount (sum of squares) each variable contributed to the random forest, the proportional amount contributed to the random forest under the "Portion" column, and a ranking by total proportion of contribution for each variable under the "Rank" column.

Table 8. Total Deaths Variance Explained

Random Forest—Total Deaths				
Predictor	**Contribution**	**Portion**		**Rank**
JASPR Presence	2157127	0.3940		1
Shooter Entrance	1523090	0.2782		2
Shooter Suicide	1125463	0.2056		3
Response Time (min)	344834	0.0630		4
AS P(hit)	145262	0.0265		5
Bystanders in Cafeteria	120325	0.0220		6
Bystanders in Classrooms	34622	0.0063		7
AS Firing Rate (rpm)	24133	0.0044		8

The results vary slightly with each generation of a random forest due to its inherent randomness, but are extremely consistent across each generation. Moreover, they align well with the results of previous analyses. The categorical variables, JASPR Presence, Shooter Entrance, and Shooter Suicide, have the greatest influence on Total Deaths. The remaining continuous independent variables, First Responder Response Time, Active Shooter p(Hit), Bystanders in Cafeteria, Bystanders in Classrooms, and Active Shooter Firing Rate, contribute substantially less. In point of fact, the top three variables account for nearly 88% of the explained variance around Total Deaths, while the remaining five variables all together explain just over 12%.

4. Total Deaths versus Categorical Variables (Active Shooter Entrance, JASPR Presence, Active Shooter Suicide)

All previous analysis suggests that each of the categorical variables has a strong impact on the response, and the regression includes a significant three-way interaction between them. Total Deaths per each combination of these variables is explored via a set of boxplots. Figure 38 displays these boxplots, separating them by JASPR Presence with the first set of six on the left showing Total Deaths without JASPR Presence and the second set of six on the right showing Total Deaths with JASPR Presence. Each of these sets of six are further separated by Active Shooter Entrance Location, with colors corresponding to those identified in the Methodology chapter. Each subset of boxplots is separated a third time, with a "No" or "Yes" indicating Total Deaths by Active Shooter Suicide.

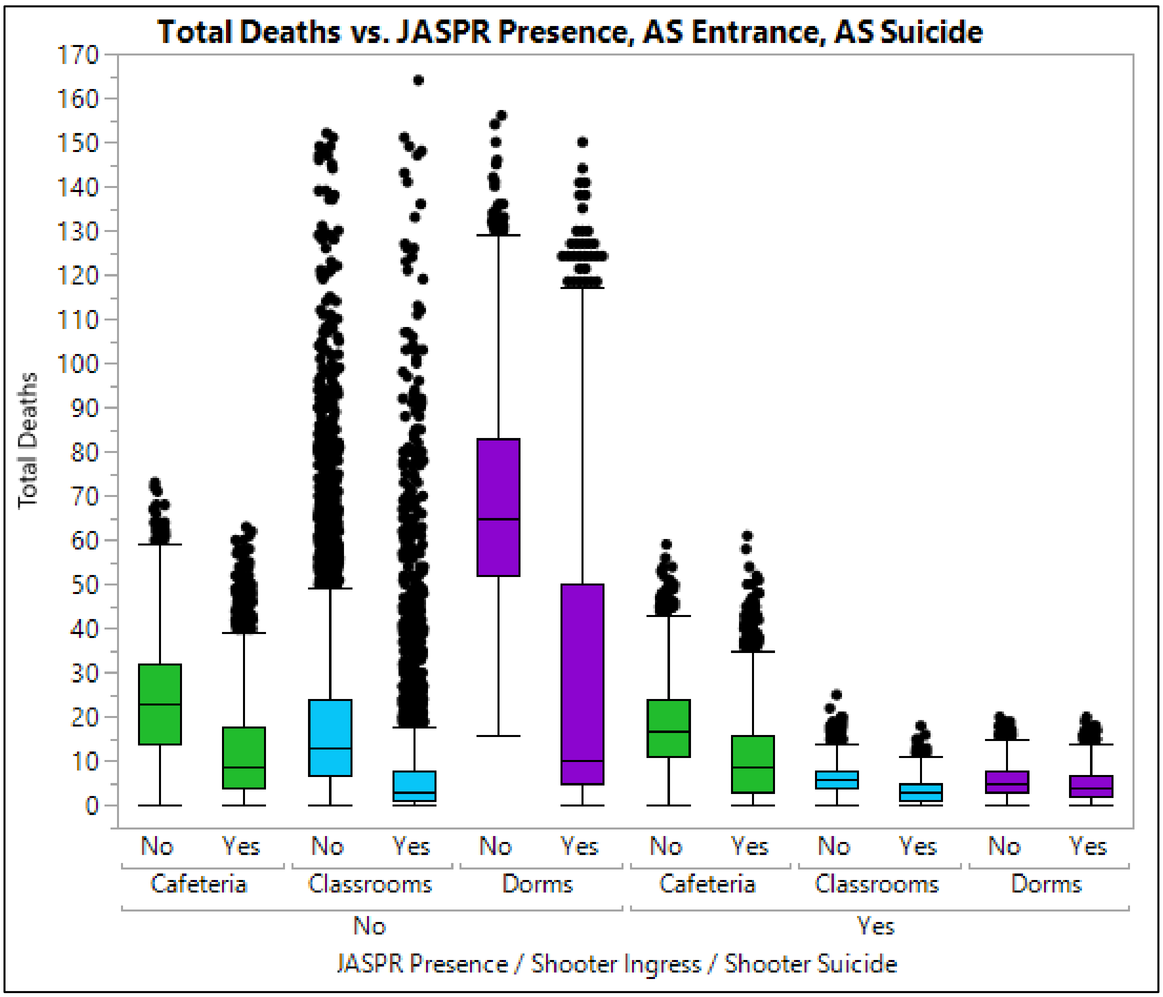

Figure 38. Total Deaths versus the Three Categorical Variables.

Figure 38 captures the sometimes-dramatic differences in Total Deaths depending on these categorical variables and also offers a few insights into their relationships. First, differences in Total Deaths depends heavily on JASPR Presence. A visual comparison of the left half of the figure against the right half of the figure provides ample evidence that the presence of a JASPR system powerfully affects the variable of interest. Second, Figure 38 expresses how critical an active shooter's entrance location is when determining Total Deaths, both with and without the presence of a JASPR system. For example, the Total Deaths in a dorm room entrance scenario with JASPR compared to a dorm room entrance scenario without JASPR is relatively high. However, the difference in Total Deaths for a cafeteria entrance scenario with and without JASPR is comparatively far less. Finally, the active shooter's suicide reduces Total Deaths by roughly the same proportions, depending on the shooter's entrance and the presence of JASPR.

VI. DISCUSSION

A. JASPR EFFECTIVENESS

The analysis performed suggests that JASPR is, overall, extremely effective in reducing the total number of deaths. However, JASPR's effectiveness depends heavily on the active shooter's entrance preference and decision to suicide or not. Other independent variables tested within the model affected the total number of deaths by the end of each run as well, though they did so to a much lesser extent. Figure 28, "Total Deaths by JASPR Presence," presents clear evidence that a JASPR presence dramatically reduces Total Deaths, regardless of other variables. The boxplot for Total Deaths, discussed in more detail in the Results and Analysis chapter, demonstrates the obvious reduction in Total Deaths when JASPR is present and the difference is stark. This evidence is echoed again, though with more detail, in Figure 38 (Total Deaths versus All Categorical Variables [Active Shooter Entrance, JASPR Presence, & Active Shooter Suicide]). The figure shows that the difference in Total Deaths is greatest when the AS entered at the dorm room entrance, failed to suicide, and no JASPR is present compared to the same set of circumstances when JASPR was present. Moreover, repeated construction of a random forest consistently demonstrated that JASPR presence is the single most discriminatory factor in determining the extent of Total Deaths. Finally, the partition tree presented for Total Deaths, perhaps unsurprisingly after the results of the random forest, shows that JASPR presence is the most important factor. A claim that JASPR may be the single most important variable for determining total fatalities in a real-world scenario, at least insofar as the model reflects the circumstances and physical layout of the USMAPS building at West Point, NY, seems reasonable at this point.

1. Circumstances where JASPR Was Least Effective

A simple examination of the evidence presented in the Results and Analysis chapter indicates that JASPR is least effective when the active shooter begins firing in the cafeteria. The difference in Total Deaths between JASPR and non-JASPR scenarios within the cafeteria is by far the smallest when compared to the dorm room and classroom entrances.

This may be due to the multiple exits available, the large number of people the cafeteria typically accommodates, and a likely much smaller cognitive delay among the personnel in immediate and obvious danger when an active shooter opens fire on a crowd. The immediate sound and sight of an active shooter firing at a crowd would reasonably cause a bystander to summon the local first responders faster, and as a consequence, end the shooting more quickly. Further, as the active shooter reveals himself at once with the first shot in a crowd, the personnel in the remainder of the building would likely be notified—either through one of JASPR's alert mechanisms (the LED marquee, an alert beacon, a flashing wall light, etc.), through one of the building's broadcast systems, or possibly even word-of-mouth as people flee away from the shooter.

JASPR is generally more effective at reducing Total Deaths when the active shooter enters the classrooms section of the building, compared to entry within the cafeteria section of the building. Unlike scenarios where the active shooter opens fire in the cafeteria, the classrooms did not typically hold as many bystanders and are less dense in comparison. However, it requires just one bystander to realize a shooting is in progress, bypass the active shooter if they are in the same classroom, and activate the emergency duress button in the hallway's center. Additionally, five of the eight total classrooms shared entrances with adjoining classrooms, allowing students in classrooms with double entrances additional opportunities to avoid the active shooter. An active shooter opening fire in the first classroom adjacent to his starting point would have alerted students in the adjacent classroom. At least in this model, shared entrances benefitted bystanders in the classrooms since each classroom has an additional exit. Other bystanders outside a classroom may overhear the shooting in progress and activate JASPR by the same method. Once JASPR is activated, it automatically triggers door locks preventing entry into a location. These locked doors prevent or dramatically slow down the active shooter from entering more classrooms and continuing to kill.

2. Circumstances where JASPR Was Most Effective

The dorm room scenarios showcase JASPR at its most effective. Figure 23 captures the relatively extreme differences in Total Deaths for dorm room scenarios with JASPR versus those without JASPR. The layout of the dorm room section of the building is similar to the classrooms section, but far more compartmentalized and with an even smaller potential concentration of people per room. The results around the dorm rooms are a bit unexpected: they offer limited exposure of a few bystanders at a time to the active shooter rather than a much larger set of targets such as the cafeteria or the classrooms might offer. But this works to the shooter's advantage since bystanders in adjacent rooms are typically unaware of the active shooter's presence and therefore incapable of alerting others, whether through activation of a duress button or by word-of-mouth.

Moreover, bystanders confronted with an active shooter have limited reaction time and only one entrance or exit. Bystanders walking the dorm room hallway also have limited ability to alert the remainder of the building, much less the individual or set of individuals within each dormitory room along this section of the building. These individuals are also targets for the active shooter and are often forced to flee first before they can react and summon first responders. The introduction of JASPR turns this set of circumstances on its head: activating JASPR, and consequently the automatic door locks associated with JASPR, blocks active shooter access into individual dorm rooms, and dramatically reduces Total Deaths from that point forward. Just as critically, the presence of emergency duress buttons allows fleeing bystanders to activate JASPR and alert the entire dorm room wing of the building at once.

B. LIMITATIONS

1. External Validity

In the most general sense, this study's external validity, the "problems of generalizing from the experiment to a larger population" (Bailey, 1994) should be questioned. That is, although the results of the agent-based model may be perfectly appropriate for the specific circumstances they model, do these results extend to other similar locations? This study is necessarily limited in scope to study the efficacy of JASPR in one location and several variables under controlled circumstances for easy study. However, until further research can verify that this model's results apply more broadly, this experiment can only suggest that they do.

2. JASPR Assumptions

Assumptions made in the model about JASPR also present limitations to the analysis. JASPR, as a system of active shooter defeat mechanisms, is either “on” or “off” for the model runs used in this analysis. This allows JASPR to bring to bear every possible mechanism at its disposal during an active shooting, or not. This inhibited a more nuanced analysis of JASPR effectiveness.

3. Casualties versus Fatalities

Only fatalities are recorded in this experiment, though this is obviously not a realistic assumption for most active shootings. However, differentiating between victims by whether they are immediately killed, or not, is not necessarily a function of JASPR’s presence, and so is deemed superfluous for this study.

C. FUTURE RESEARCH

Many of the suggested areas for future research bear on the limitations discussed in the previous section.

1. Expanding Physical Layout of Model

This study uses the second floor layout of the USMAPS building located at West Point, NY. Future studies might examine models corresponding with different structures, or even move the model to an outdoor scenario. Several of JASPR’s active shooter defeat mechanisms rely on, or are optimally designed to function in, an indoor setting. Experimenting with the effectiveness of each of these mechanisms over multiple different settings would likely refine and add to existing research on active shooter defeat mechanisms. Mirroring other locations while studying JASPR’s efficiency in an agent-based model may bolster the evidence presented in this study that JASPR is effective.

2. Additional Variables

Incorporating additional variables into the model for study is another avenue for future research. For example, the total number of injuries went unexamined in this study. Because only total fatalities are studied, and not total casualties, future research might examine the total casualty rate. The total casualty rate is likely higher than simply the Total Deaths variable presented here, and it may suggest a different employment for JASPR. First Responder Response Times in conjunction with JASPR Presence might also study how many additional lives are saved by the timely arrival of medical first responders.

3. Scope of Current Variables

Similarly, improving how relationships between the independent and/or conditional variables in this study might prove fruitful. For example, Active Shooter p(Hit) and Active Shooter Firing Rate almost certainly share an inverse relationship, but the tradeoff between the two variables is not known, and how they should interact during an active shooting in the hands of a shooter who may have either little, or extreme, skill in handling a firearm would have been too difficult to model. Additionally, mapping Total Deaths to recorded First Responder Response Times to alarms at West Point, NY, may yield further insights into JASPR effectiveness. These response times, along with Blair et al.'s (2014) study of response times to active shootings between 2000 and 2010 are provided in Figure 39 and Figure 40, respectively, in the Appendix.

4. Cost Estimation of JASPR

Finally, any serious employment of the JASPR system, or subset of its systems, requires a cost estimate of this system. After such an analysis is completed, a more informed cost-benefit analysis might take place into how to most efficiently employ JASPR to prevent needless casualties.

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VII. CONCLUSION

This study examines how effective JASPR, a suite of active shooting defeat mechanisms, may be at reducing the total fatalities in a simulated environment. An agent-based model simulating an active shooting on the second floor of the USMAPS building at West Point, NY, was created to assess this. Several variables that potentially impact the behavior of the active shooter are examined, including the shooter's entrance choice, whether the shooter suicides at some time after the first shot, rate of fire, and the shooter's p(Hit). The model also incorporates varying levels of bystanders, differing First Responder Response Times after dispatch, reaction time by the bystanders, and of course whether JASPR is present at the time of the shooting.

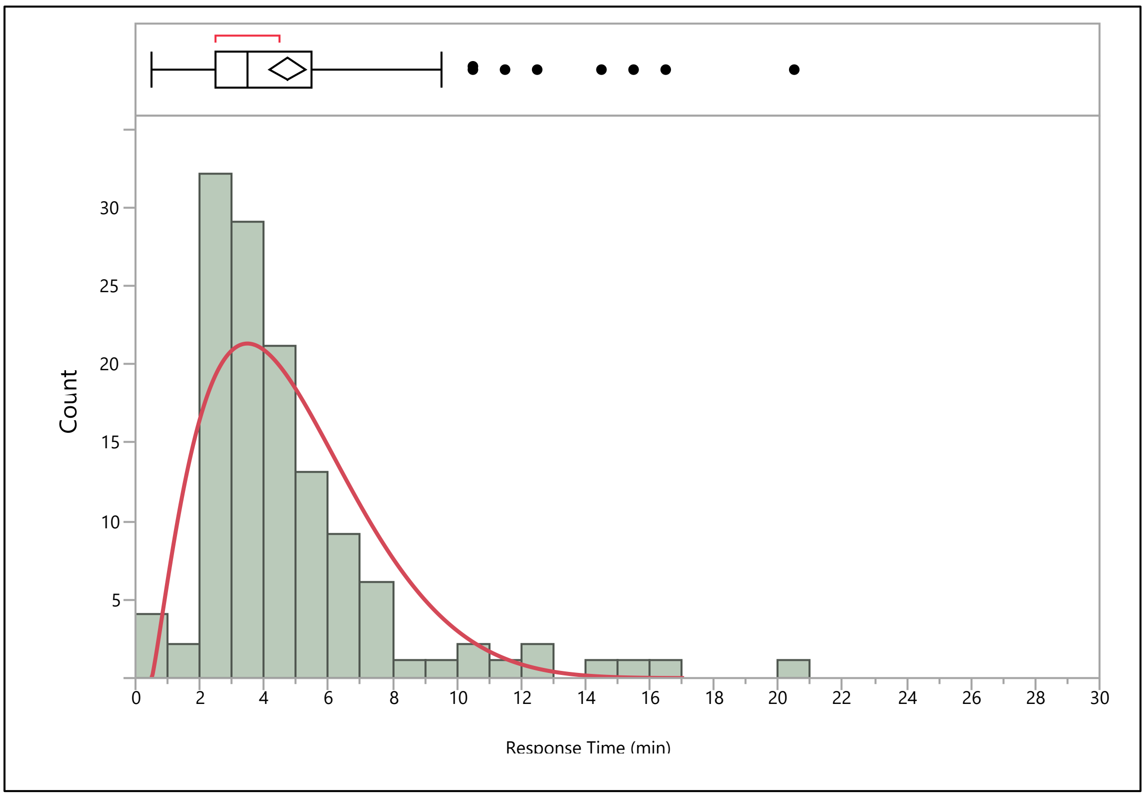
The results from the model suggest that JASPR significantly reduces the total number of deaths, depending on the set of circumstances around the shooting. JASPR is at its most effective when the active shooter opens fire within the dorm room section of the building. This is likely due to the isolation of the bystanders and their general inability to call for help or alert other people in the area to the presence of a shooter. JASPR provides a quick and effective way to summon first responders, alert the remainder of the building, and automatically lock all door room doors when an active shooter is present. JASPR is least effective when the active shooter opens fire on the set of bystanders within the cafeteria. The active shooter announces himself with the first shot to a large number of people in these cases, and has limited time and opportunity to target a subset of the cafeteria bystanders before they flee out of range. Active shootings that begin in the classroom section of the building still show JASPR as a marginally effectively tool in reducing the number of Total Deaths in the model. Compared with the dorm-room setting, the active shooter has larger crowds to fire on, but the larger number of bystanders also makes it more likely that someone will manually trigger JASPR or that gunshot detector will automatically trigger JASPR.

Although the results presented in this study are limited to the model they are based on, JASPR's potential in this study suggests more research into a set of active shooter defeat mechanisms is warranted. Ultimately, such research may reduce the scale of such horrific events—and, at least in some cases, prevent them.

APPENDIX

A. EMERGENCY ALARM RESPONSE TIMES AT WEST POINT, NY

The West Point, NY, Military Police (MPs) were gracious enough to supply their recorded response times to emergency alarms at West Point (Correira, K. & Cruz, P., email to author, February 28, 2020). This data reflects 127 responses to emergency alarms including fire alarms, elevator distress calls, intrusion detection alarms, and other similar calls. Figure 39 displays a histogram and boxplot of this data, coupled with a suggested beta distribution. This distribution would likely prove useful for modeling future active shooter defeat systems.



Suggested Beta Distribution

Figure 39. Histogram of Actual First Responder Response Times for West Point MPs

Table 9 provides the suggested beta distribution parameters associated with Figure 39.

Table 9. Suggested Beta Distribution Parameters

Type	Parameter	Estimate	Lower 95%	Upper 95%
Shape	α	2.2208761	1.7410753	2.7870941
Shape	β	7.9659792	6.1018666	10.171013
Threshold	θ	0.5		
Scale	σ	20		

B. FIRST RESPONDER RESPONSE TIMES TO ACTIVE SHOOTER EVENTS

In Blair et al's (2014) study of 110 active shootings between 2000 and 2012, the authors characterized their associated police response times with the histogram shown in Figure 40.

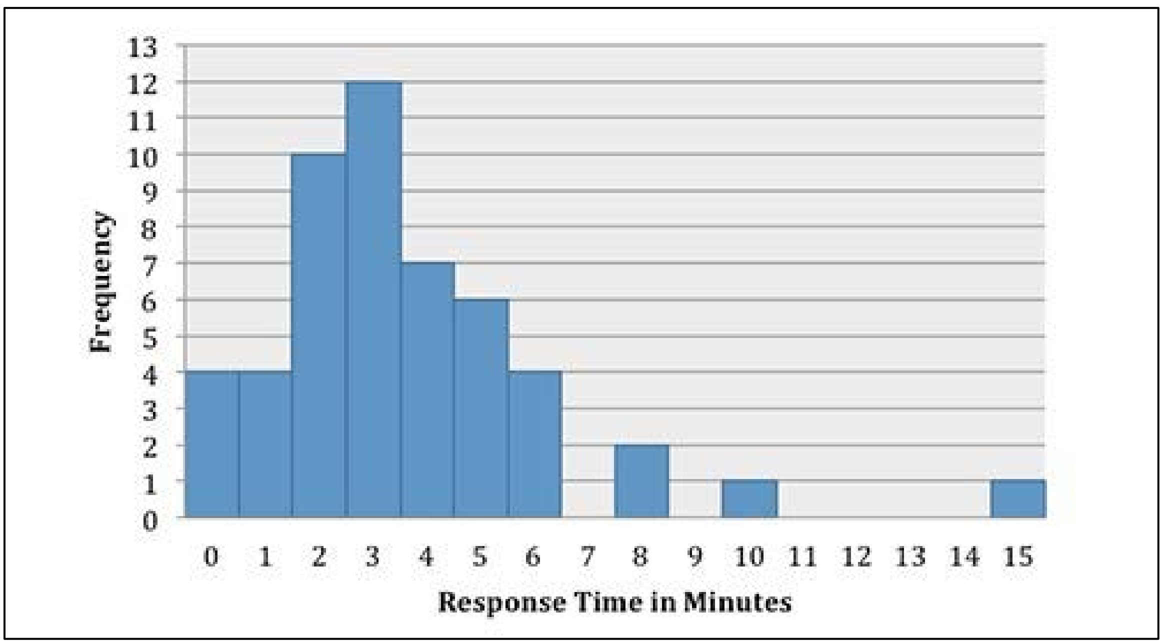


Figure 40. Police Response Time. Source: Blair et al. (2014).

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